AIR TRAFFIC ORGANIZATION

Operational Performance Summary for Selected ATO Capacity and Efficiency Initiatives

July 2004

Office of Operations Planning – Performance Analysis

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EXECUTIVE SUMMARY

The Federal Aviation Administration's Air Traffic Organization (ATO) has many initiatives designed to improve the quality of services provided to its customers. The full scope of these initiatives is described in the ATO's Operational Evolution Plan (OEP). The ATO aspires to be a performance-based organization, and as such requires that decisions about improvements to the air traffic control infrastructure and procedures be based on quantitative measures. This report focuses on a few select programs that currently are being deployed to the National Air Space (NAS), and summarizes the observed benefits of these systems.

Increased Arrival and Departure Rates

A primary goal of the OEP is to increase the arrival and departure capacity of the nation's airports. The most direct way to achieve this goal is to build new runways at congested airports. However, runway construction is expensive and time-consuming, and so the ATO also is developing new technologies that maximize the use of existing runways. Traffic Management Advisor (TMA) is one such program, which is used by en-route controllers to optimize the arrival flow at capacity constrained airports, resulting in reduced delay. TMA has been deployed to eight of the twenty en route centers in the contiguous United States, the most recent of which was Houston Center (ZHU) in June 2003. Measured benefits for the other sites are reviewed in this report, but as ZHU was the only site to become operational in the past year, we focus on it. TMA was installed at Houston Center to increase the arrival rate at George Bush Intercontinental Airport (IAH). Houston Center began using Time-Based Metering (TBM) in December 2003, at the same time that a new runway was opened at IAH. Because of these simultaneous changes we have been unable to isolate the impact of TBM, but there has been an upward shift in the distribution of arrival rates at the airport since these changes became operational. We believe that TBM also reduced internal departure delays by nearly four minutes. Further, during times when TBM is used, the average distance flown by arriving aircraft from 200 nmi out is reduced by 3 nmi.

Four of the OEP 35 airports have added new runways since September 2003. Since its new runway opened, the AAR at Miami International Airport (MIA) has increased from a typical value of 64 aircraft per hour to an average rate of 68, and often is 72 aircraft per hour. During visual approach peak periods, the actual arrival rate increased from 14.0 to 15.3 aircraft per quarter hour, and the departure rate from 13.4 to 14.1 aircraft per quarter hour. During instrument approach peak periods the arrival rate increased from 9.2 to 11.4 aircraft per quarter hour. Denver International Airport (DEN) opened a new runway, which is primarily used for departures, in September 2003. At DEN during busy periods, the arrival rate increased from 24.1 to 26.3 aircraft per quarter hour when two arrival runways are being used, and from 23.1 to 25.9 per quarter hour when three arrival runways are being used. The new runway at Denver also reduced taxi-out times by 23 seconds when departure demand was high.

The situation at the other two airports that opened new runways in the past year is different from that of MIA and DEN. Both IAH and Orlando International Airport (MCO) closed existing runways for refurbishment when the new ones opened. The analysis of IAH results is further complicated by the addition of TMA and high-speed taxiways. At Orlando, the new runway is parallel to the one that was shut down for improvements, and no capacity benefits are expected until the pre-existing runway is reopened.

Improving the efficiency of ground movement at airports can increase the overall throughput of the aviation system, and the ATO has been testing several different tools to improve surface movement coordination. The Airport Target Identification System (ATIDS) at Detroit Wayne County Metropolitan Airport (DTW) provides accurate aircraft position information from multilateration sensors to Northwest Airlines (NWA). Northwest Airlines has experienced improved ramp efficiency, saving 23 seconds of taxi time per aircraft during arrival and departure pushes because flights can push straight back. This equates to a savings of 2,464 hours of taxi time annually. ATIDS has also provided benefits in inclement weather, saving approximately 32 hours of taxi time annually in fog, and helping NWA to avoid 20 to 24 cancellations thanks to more efficient deicing. Communication workload between NWA aircraft and facilities decreased by 27 percent. It is estimated that 89 hours of delay were saved using reroutes to avoid en route restrictions, and 432 to 720 hours of delay were saved due to improved situational awareness during deicing events.

Airport Surface Detection Equipment-Model X (ASDE-X) is another multilateration system that is being used at Dallas Fort Worth International Airport (DFW). ASDE-X provides real-time aircraft position and identification information to the airport, American Airlines, and Delta Air Lines. This information sharing reduced Delta taxi-out times in visual approach conditions by more than 90 seconds per flight in comparison with other operators who did not participate. ASDE multilateration data sharing at Memphis International Airport (MEM) reduced taxi-out times for FedEx by over 1 minute in visual approach conditions and over 4 minutes in instrument approach conditions (for one airport configuration). The percentage of flights with taxi-out times in excess of 40 minutes has decreased by half with improved surface surveillance. Decreased taxi-out times at MEM are saving FedEx $1.8 million per year.

Decreased En Route Congestion

Several of the programs reported on in this document are designed to decrease congestion in and improve the efficiency of the en route airspace. The first of these is the Flow Evaluation Area/Flow Control Area functionality, a Traffic Flow Management (TFM) decision support capability that was added to the Enhanced Traffic Management System (ETMS) in the spring of 2002. An FEA is an arbitrary volume of airspace that a traffic manager constructs to evaluate the effects of constraints on the flow of aircraft. Once constructed, an FEA provides a list of flights that are projected to pass through it. An FCA is a similar airspace section, but a flight expected to pass through an FCA must be rerouted. Since FEAs and FCAs began to be used operationally in June 2003, the number of FEAs has increased steadily, indicating that traffic flow managers find them useful. This report includes a number of anecdotes that indicate FEAs and FCAs have reduced the number and severity of Miles-In-Trail restrictions issued.

The User Request Evaluation Tool (URET) is a decision support tool for en route air traffic controllers, and has been deployed to half of the en route centers in the continental United States. URET is a classic automation tool in that it reduces the use of the paper strips that are used to keep track of aircraft, thereby increasing controller productivity. URET also automatically detects conflicts between aircraft twenty minutes in advance, and between aircraft and airspace forty minutes in advance. This trial planning functionality in principle can allow controllers to give conflict-free reroutes, either to avoid traffic constraints such as severe weather or in response to pilot requests. Deployment of URET began in 1999, and as of February 2004 ten centers have received the tool. The remaining ten centers in the continental U.S. will receive URET by the end of 2006. Controller acceptance of URET has been good, with all sectors using URET at eight en route centers, and over 80 percent of sectors using the tool at the other two centers. An additional indication that controllers find URET useful is that more than 15 percent of all route-shortening flight plan amendments (or "directs") given to aircraft in URET centers come from the tool, with some centers showing considerably higher usage. Controllers are using URET to reduce flight distances, which saves users money. The data show that the number of such amendments has dramatically increased since the deployment of URET, and as a result users are saving over 60,000 nautical miles per day - over $13 million per month in direct operating costs - in all URET centers.

The final en-route program discussed in this report is the Advanced Technologies and Oceanic Procedures program, or ATOP. ATOP modernizes the way in which air traffic controllers communicate with pilots in the oceanic en route environment, replacing high-frequency voice communications with a satellite-based data link, and in the process eliminates the need for an intermediate radio operator. The oceanic data link has been in use in one of the three oceanic en route centers since 1999, and nearly 28 percent of flights in the equipped center communicate with air traffic control using it. Usage by equipped aircraft is even higher, with 98 percent of such flights using data link. Switching to data link is already benefiting aircraft by reducing controller response time. Prior to the introduction of oceanic data link, a response to a request for a route or altitude change for severe weather avoidance would typically take four to five minutes. With data link, such requests now take two minutes. Route and altitude changes to avoid weather are considered safety critical, but even pilots requesting altitude changes for non-critical reasons are experiencing reduced response times. Before data link, such requests faced a response time of seven to eight minutes; now, response times are three to four minutes.

Improved Flight During Unfavorable Airport Weather Conditions

Perhaps the greatest challenge in managing the air traffic control system is responding to inclement weather. Thunderstorms, poor visibility, icing, and other weather events can lower arrival and departure rates at airports, and reduce capacity in the en route environment. A new surveillance technology, ADS-B, combined with a new visualization tool for pilots, the Cockpit Display of Traffic Information (CDTI), is being tested by United Parcel Service (UPS) at Louisville Standiford Airport. CDTI may enable visual approaches in marginal weather conditions. In visual approach conditions, CDTI is saving UPS 2 to 4 nautical miles per arriving flight from 40 nmi to the runway, depending on the airport configuration. UPS is also saving 0.5 nmi per arriving flight from 100 nmi to 40 nmi from the airport. CDTI is saving UPS fuel, with excess fuel burn reduced from 6.6 to 5.9 percent.

Improved Flight During Severe En Route Weather Conditions

Another weather tool the ATO is developing is the Corridor Integrated Weather System (CIWS), a weather display and forecast tool that presents a unified view of data from different sensors to traffic managers in near-real-time. CIWS also provides short and near-term forecasts of weather. Improved weather information can improve the ability of controllers to respond to adverse weather conditions. This report includes several case studies that show positive results using CWIS. For example, in one weather event in Boston Center, savings are estimated to be at least $6 million.

1 INTRODUCTION

In order to be more responsive to the needs of airspace system users, to provide more value to the taxpayers, and to better empower its employees, the Federal Aviation Administration (FAA) has recently reorganized its Air Traffic Control (ATC) operations, research, and development organizations into the Air Traffic Organization (ATO). The ATO's goal is to provide a cost-effective and capacious airspace system, while ensuring safety and security. In order to accommodate expected future increases in the demand for air travel and air cargo shipments, the ATO is collaborating with other organizations on a number of initiatives to increase the capacity and efficiency of the National Airspace System (NAS). These initiatives are outlined in the ATO's Operational Evolution Plan (OEP).[1]

The OEP is an ongoing ten-year plan developed by the FAA to increase the capacity and efficiency of the NAS, while at the same time enhancing safety and security. The plan specifically addresses air transportation services delivered to our customers. It reflects collaboration with the aviation community, including the airlines, cargo carriers, general aviation, airports, manufacturers, the Department of Defense (DoD), the National Weather Service, and the National Aeronautics and Space Administration (NASA).

To make sure that the projected capacity and efficiency benefits that are outlined in the OEP are actually realized, the ATO's Operations Planning Performance Analysis organization is charged with measuring any operational improvements following implementation of these initiatives. The Performance Analysis staff includes highly experienced operations analysts, statisticians, economists, and database experts with broad knowledge of the NAS. The Performance Analysis staff are continually evaluating the effects of new and refined systems and techniques on the NAS. Performance Analysis is also working to understand how factors outside of the FAA's control, such as severe weather and aircraft fleet changes, affect the system's performance.

This is the first of what are planned to be annual reports on the *actual* operational effects of OEP initiatives. These effects are assessed using a wide variety of analytical and data-gathering techniques, with an emphasis on validation of analytical results with operators and users of the system (e.g., air traffic controllers, air traffic managers, dispatchers, airline planners, airport managers, etc.). The organization of this report follows that of the OEP, whose initiatives are mapped into four broad objectives:

1. Increased arrival and departure rates,
2. Improved flight during unfavorable airport weather conditions,
3. Decreased en route congestion, and
4. Improved flight during severe en route weather conditions.

In each semi-annual report we will focus our analyses on those initiatives that have become operational and had a significant impact in the past 6 to 12 months. In this report we feature the following operational improvements:

Increased arrival and departure rates

[1] http://www.faa.gov/programs/oep/

- Traffic Management Advisor (TMA)
- New runway construction (specifically Miami International, Denver International, and Houston’s George Bush Intercontinental airports)
- Surface movement coordination

Decreased en route congestion

- Flow Evaluation and Flow Constrained Area Functionality of the Enhanced Traffic Management System (ETMS)
- User Request Evaluation Tool (URET)
- Advanced Technologies and Oceanic Procedures (ATOP)

Improved flight during unfavorable airport weather conditions

- Automatic Dependent Surveillance – Broadcast (ADS-B)

Improved flight during severe en route weather conditions

- Corridor Integrated Weather System (CIWS).

2 INCREASED ARRIVAL AND DEPARTURE RATES

There are two main strategies to help airports meet peak demand: build new runways; and maximize the use of existing runways. A new runway can increase airport capacity and efficiency, but a runway can take ten years to plan, construct, and commission. Currently, the OEP includes ten runways planned at benchmark airports. A combination of air traffic procedures, new technologies, improved airspace design, surface management, and decision support tools are proposed to make better use of existing runways. Procedures will be evaluated for crossing runway configurations at a number of benchmark airports. Terminal airspace redesigns, planned for most of the benchmark airports and metro areas, are aimed at improving the transition of arrivals and departures. Traffic management advisory tools, which help in managing the arrival stream, will become operational at four additional sites. Also, the multi-center capability will be evaluated in the Philadelphia area. Surface management systems are being explored for operational use later in the decade.

In this report we examine the operational impact of Traffic Management Advisor (TMA), recent new runway construction, and Surface Movement Coordination.

2.1 TRAFFIC MANAGEMENT ADVISOR (TMA)

2.1.1 System Description and Overview

TMA assists controllers with arrival aircraft in the en route cruise and transition airspace managed by ARTCCs. TMA provides ARTCC personnel with a means of optimizing the arrival throughput of capacity-constrained airports, thereby reducing delay. The resulting uniformity of arrival flows can also lead to an increase in departure rates and a decrease in departure delays.

Inputs to the TMA system include real-time radar track data, flight plan data, and a three-dimensional grid of wind speeds and directions. TMA trajectory models use this information, updated every 12 seconds, to optimize schedules to the meter fixes for all arriving aircraft which have filed Instrument Flight Rules (IFR) flight plans, with consideration given to separation, airspace, and airport constraints. These optimized schedules may then be displayed on controller radar displays, and used to ensure a smooth, efficient, and safe flow of aircraft to the terminal area.

In addition to this Time-Based Metering (TBM) function, TMA provides traffic managers with a more accurate depiction of arrival demand versus capacity for an airport, by runway and arrival fix. Traffic managers use this information to optimize the application of Miles In Trail (MIT) restrictions, leading to more efficient flows and better use of airport capacity. Traffic managers also use TMA to optimize the release of departures from smaller airports in their centers that are traveling to the main airport. Traffic managers typically begin using these “strategic” TMA functions before TBM becomes operational.

TMA currently operates at eight ARTCCs. At each ARTCC, TMA computes arrival schedules for a specific airport. At Los Angeles Center (ZLA), Atlanta Center (ZTL), and Houston Center (ZHU), the TMA system benefits from an Adjacent Center Data Feed (ACDF), which allows for more coordination outside the center. Table 2-1 lists the deployed sites.

In this document we present the following TMA analyses:

- An examination of IAH arrival rates
- A study of the various delays (departure, en-route, and arrival) for flights originating within ZHU airspace bound for IAH
- A flight distance analysis for several arc rings of IAH from 200 nmi to the runway
- An examination of the use of TBM at Los Angeles Center for LAX arrivals.

Table 2-1. Deployed TMA Sites

ARTCC		Airport	
Name	**Identifier**	**Name**	**Identifier**
Fort Worth	ZFW	Dallas/Fort Worth International	DFW
Minneapolis	ZMP	Minneapolis-St. Paul International	MSP
Denver	ZDV	Denver International	DEN
Los Angeles	ZLA	Los Angeles International	LAX
Atlanta	ZTL	Hartsfield-Jackson Atlanta International	ATL
Miami	ZMA	Miami International	MIA
Oakland	ZOA	San Francisco International	SFO
Houston	ZHU	George Bush Intercontinental	IAH

2.1.2 Summary of Previous TMA Results

The Free Flight Program Office (FFPO) Metrics Team has reported extensively on the operational benefits of TMA. We describe here a summary of their general and center-specific findings. In general, the FFPO Metrics Team has found that:

- TMA increases arrival throughput and thereby reduces arrival delays.
- At some airports with shared runways, overall operations rates increased (arrivals plus departures) during arrival peaks.
- When used by traffic managers as a planning tool, TMA reduced holding, flight times, and departure delay for airports controlled by the TMA ARTCC (so-called "internal departures").

ZFW was the first TMA implementation site. ZFW began TMA operations before the establishment of the Free Flight program, concurrent with the redesign of DFW terminal airspace. NASA Ames Research Center analyzed the impact of TMA at ZFW [Ref. 1], finding a reduction in delay of 70 seconds per arriving aircraft during periods when demand exceeded capacity. Additionally, they found that the Terminal Radar Approach Control (TRACON) increased the AAR by 5 percent.

At ZMP, the Traffic Management Unit (TMU) uses TMA as a strategic planning tool and controllers use TMA for tactical TBM. Initial Daily Use (IDU) of TMA for MSP arrivals began in June 2000. The FFPO Metrics Team reported increases in actual operations rates at MSP of 4 and 5 operations per hour (4 to 5 percent increase) under visual and instrument conditions, respectively [Ref. 2]. Initially, they found no discernible change in the AAR at MSP. However, after MSP TRACON traffic managers were given a TMA display, the AAR was found to increase by 0.7 (visual) and 1.4 (instrument) arrivals per hour [Ref. 3]. As further evidence of benefit, an examination of flight distances in the terminal area showed decreases of 5 nmi (visual) and 9 nmi (instrument), and a redistribution of delay to higher, more fuel-efficient altitudes [Ref. 2].

TMA daily use at ZDV for DEN arrivals began in September 2000. While DEN has excess capacity at most times, there are times during poor weather where demand exceeds capacity and delays accrue. An assessment of TMA during these times by the FFPO Metrics Team found that the tool increased arrival rates by 1 (visual) to 2 (instrument) aircraft per hour (2 to 4 percent increase) [Ref. 2]. They found that most of the time, air traffic managers use TMA to make strategic decisions about MIT restrictions. Benefits from TMA should increase at ZDV/DEN as demand increases.

Active use of TMA started at ZLA for arrivals to LAX in June 2001. Initially, ZLA traffic managers used TMA as a strategic tool to determine the necessity of location-based MIT restrictions. Controllers at ZLA began testing time-based metering of arrivals in May 2002. Initial studies by the FFPO Metrics Team focused on the use of the tool by traffic managers for planning and management. Reference 3 reported a 3 percent increase in actual arrival rates, and a small (1.5 percent) increase in AAR during instrument conditions. Reference 2 also reported a 12 percent decrease in holding for arrivals, and a 34 percent decrease in combined gate and airborne delay for internal departures. Soon after ZLA started TBM, the FFPO Metrics Team found a further 5 percent increase in arrival rates during instrument conditions [Ref. 4]. In reference 5, they reexamined internal departure delays to LAX finding an additional 23 percent decrease in combined gate and airborne delays. The FFPO Metrics Team also began examination of MIT restrictions inside ZOA airspace for flights entering ZLA airspace. They found that after TBM was implemented at ZLA, the number of MIT restrictions and the length of time they were active decreased. To measure both of these effects, the FFPO Metrics Team developed a restriction value metric (actual MIT x time restriction active) that decreased by 24 percent after TBM. Also in May 2003, ZLA began to receive an Adjacent Center Data Feed (ACDF) from the ZOA TMA system. ZLA uses this feed to better handle traffic from ZOA airspace including the setting of restrictions between the ARTCCs. Most recently [Ref. 6], they reported on how ACDF has been used by ZLA to better manage ZOA departures headed for LAX ("internal departures"). With ACDF, ZOA traffic managers can use TMA to schedule the release of their departures bound for LAX.[2] During the ACDF period spanning May to October 2003, when compared with a similar period during 2002, the gate delay showed a 47 second (11 percent) decrease after ACDF, while the gate delay counting early flights showed a 112 second (39 percent) decrease.

[2] ZOA controllers will soon be able to meter traffic headed for LAX within their airspace using Adjacent Center Metering (ACM).

Traffic managers began to use TMA at Atlanta Center (ZTL) for ATL arrivals in June 2001. ZTL has not yet implemented time-based metering. However, in January 2003 ZTL required mandatory usage of TMA as the primary data source for the strategic planning of restrictions. Even before mandatory usage, the FFPO Metrics Team found a 24 percent reduction in total holding time when they compared June-August 2000 with the summer months of 2002 [Ref. 4]. They also found a 25 percent reduction in combined airborne and gate delay for internal departures [Ref. 3]. Focusing on the specific effect of mandatory usage of TMA, they found a 9 percent reduction in total holding time from January-April 2002 compared with the same period in 2003 [Ref. 5]. Examining 4 months before and after mandatory usage of TMA, the FFPO Metrics Team also estimated a 2.5 percent increase in the acceptance rate and increases in the actual arrival rate for both visual (+3.6 percent) and instrument (+2.5 percent) conditions [Ref. 5]. Recently [Ref. 6], they found a 22 percent decrease in the weighted product (Miles in Trail) times (MIT restriction duration in minutes), during the October-November 2003 period when compared with the same period in 2002. Overall operations at ATL in the 2003 period was found to increase by 7 percent, which gave the FFPO Metrics Team confidence that they were looking at the system during comparable conditions. In early February 2004, ZTL started receiving an Adjacent Center Data Feed (ACDF) from Jacksonville Center (ZJX). The FFPO Metrics Team found a 10 percent decrease in the weighted product of MIT restrictions (the inter-aircraft distance multiplied by the restriction duration) when comparing restrictions to ZJX from ZTL between January 2004 (before ACDF) and March 2004 (after ACDF).

TMA became operational at ZMA for MIA arrivals in May 2001. The TMU is using TMA as an aid in decision-making and strategic planning. TMA displays are also operational at the MIA TRACON, where the TMU uses the system load graph to help make decisions about airport configuration, restrictions, and staffing. ZMA has not yet fully implemented time-based metering, although they continued to run tests of TBM during 2003. After initial implementation, the FFPO Metrics Team reported a 6 nmi decrease in flight distance in the terminal area during peak arrival periods [Ref. 4]. They also examined a reduction in the flight distance variance, corresponding to increases in predictability. Further, the FFPO Metrics Team found a 46 percent decrease in combined gate and airborne delay for internal departures. In their June 2003 report [Ref. 5], they examined the initial tests of TBM at ZMA. They found that while there was not enough data for a statistically significant result, the few days of data pointed to an increase in the peak arrival rate. In addition to MIA, Miami Center controllers have begun using TBM for arrivals into Ft. Lauderdale Airport. This is the first time that TBM has been used for a secondary airport within a center.

ZOA began TMA use for SFO arrivals in August 2001. ZOA has not yet implemented time-based metering. Nevertheless, ZOA traffic managers are using TMA to help manage flows into SFO much like what was described above at ZTL and ZMA. After initial implementation, the FFPO Metrics Team reported 2.5 nmi. decrease in flight distance in the terminal area during peak arrival periods [Ref. 4]. Further, they found a 35 percent decrease in combined gate and airborne delay for internal departures

The most recent site to receive TMA is ZHU for IAH arrivals. They began operation in June 2003. In this document we further explore benefits of TMA at ZHU.

TMA will be implemented next at Chicago Center (ZAU) to help manage delays at Chicago O'Hare (ORD). TMA is expected to improve the efficiency with which ORD's capacity is used. A preliminary benefits analysis by the FFPO Metrics Team shows that a 2 percent increase in the use of Chicago's capacity could reduce delays by more than 10 percent.

2.1.3 TMA at ZHU/IAH

ZHU began daily use of TMA in June 2003, and partial use of time-based metering in December 2003.[3] Simultaneous with the start of TBM, IAH opened a new parallel runway on the north side of the field, 8L/26R (see Figure 2-1). When the new runway was opened the existing runway 8R/26L was closed for resurfacing until July 2004. To further complicate matters, work was also done on runway 9/27 and its taxi-ways (see Figure 2-2 for the timeline).

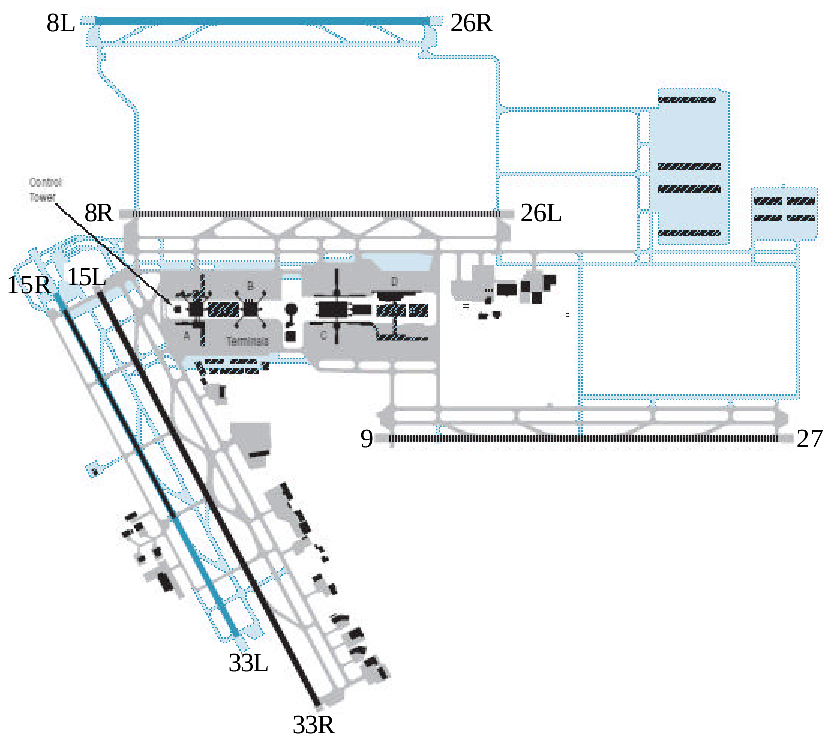

Figure 2-1. IAH Airport Layout

Because of all these simultaneous actions we are unable to properly estimate the impact of TMA time-based metering independently of other changes. Nevertheless, with anecdotal evidence from ZHU that TBM is responsible for an overall improvement in operations, we do analyze the combined effect of these changes.

The benefit analysis in this report includes an examination of the following metrics:

[3] Since IAH is close to the center boundary, flows from the northwest are metered in ZFW and ZHU airspace.

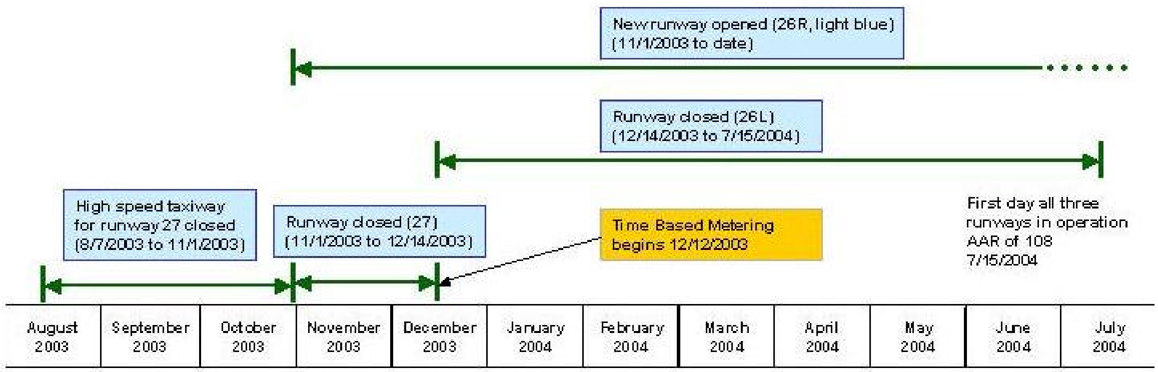

Figure 2-2. IAH Timeline

1. The actual arrival rate at IAH during peak demand periods.
2. Departure, en-route, and arrival delays to IAH from airports within the internal ZHU airspace.
3. Flight distances for IAH arrivals from a range of 200 nmi.

2.1.3.1 Peak arrivals at IAH

In this section we measure the combined effect of TMA, the new runway, and TBM at IAH on peak arrivals in 15 minute time periods. We compare the pre-TMA period January to May 2003 with the period January to May 2004, the latter period coinciding with the use of TMA, the new runway, and TBM at IAH. As mentioned above, TMA was implemented at ZHU in June 2003. IAH began using TBM in December 2003.

In Figure 2-3 we show peak arrivals for IAH in 15 minute time periods. In 2004, our focus is to capture periods when the new runway, and TMA with TBM were in use, corresponding to the time periods 0700 to 1300 and 1600 to 2100 Local Time. The 2003 data is also for these time periods.

There is a noticeable shift of the distribution to the right for the post-TMA period. In Figure 2-4 we highlight the region of 24 arrivals per 15minute period and above. Nineteen percent of the post-TMA time periods 21 and over, and 30 percent of the post-TMA time periods 24 and over correspond to times when TBM was used.

2.1.3.2 Departures from ZHU to IAH

We also assessed the effect of TBM on several delay measures for flights arriving at IAH that departed from airports within ZHU. We collected delay data from the ASPM system for the following internal departure airports:

AUS – Austin

BRO – Brownsville

BTR – Baton Rouge

CRP – Corpus Christi

GPT – Gulfport

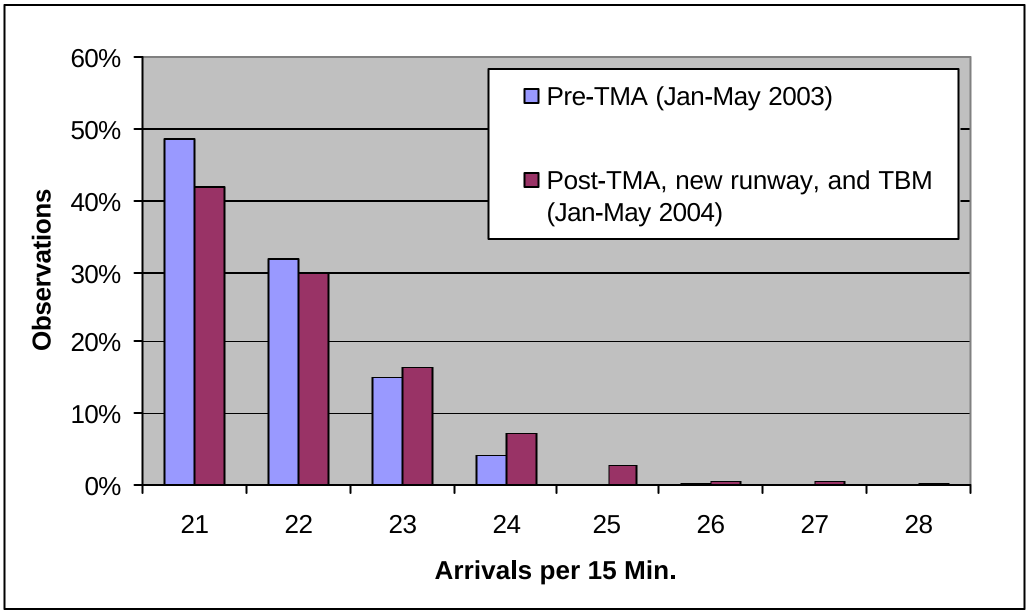

Figure 2-3. IAH Arrival Rate Distributions

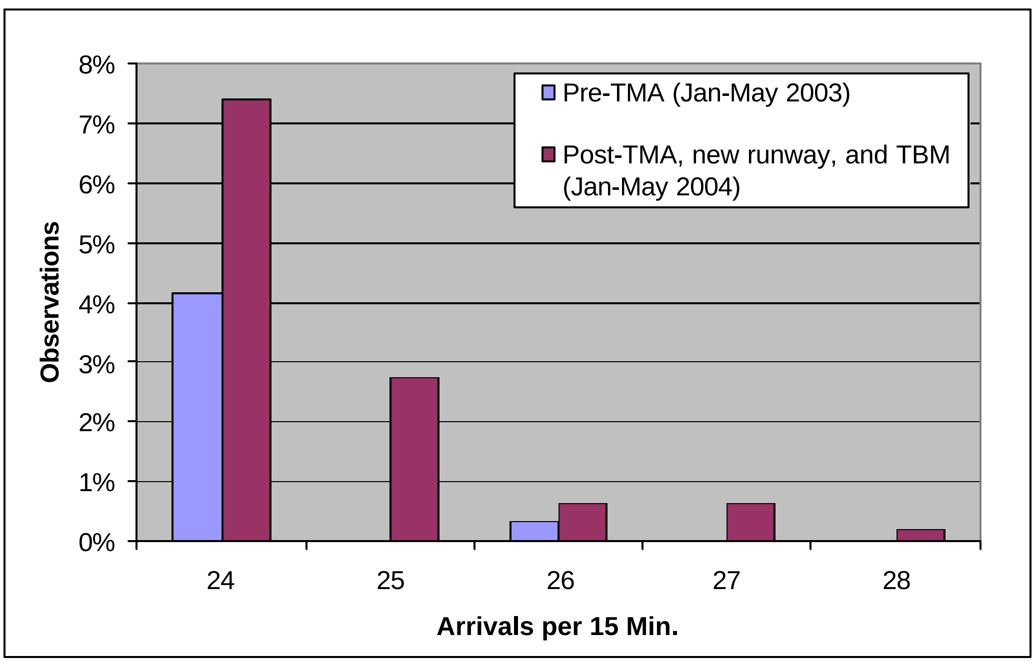

Figure 2-4. IAH Arrival Rate Distributions, 24-28 per 15 Minutes

HRL – Harlingen

LFT – Lafayette

MFE – McAllen

MOB – Mobile

MSY – New Orleans

SAT – San Antonio.

The period considered here is January to April 2004, and the comparison is between individual flights departing from internal airports with and without TBM. We made delay comparisons for times when most of the TBM periods took place (0700 to 0800 Local Time, 1100 to 1200 Local Time, 1600 to 1900 Local Time). Between January and April 2004, 15.8 percent of all internal departure flights to IAH departed when TBM was in use during the selected hours as previously defined.

The results are shown in Figure 2-5. Average departure delay according to schedule, departure delay according to flight plan, airborne delay, block delay, gate arrival delay according to schedule, and gate arrival delay according to flight plan all have decreased during the TBM periods we analyze. The most significant delay reductions are for departure delay according to schedule (43.2 percent), departure delay according to flight plan (39.1 percent), gate arrival delay according to schedule (49.6 percent), and gate arrival delay according to flight plan (46.5 percent). Reasonable delay reductions are also evident for airborne delay (20.5 percent), and block delay (27.8 percent).

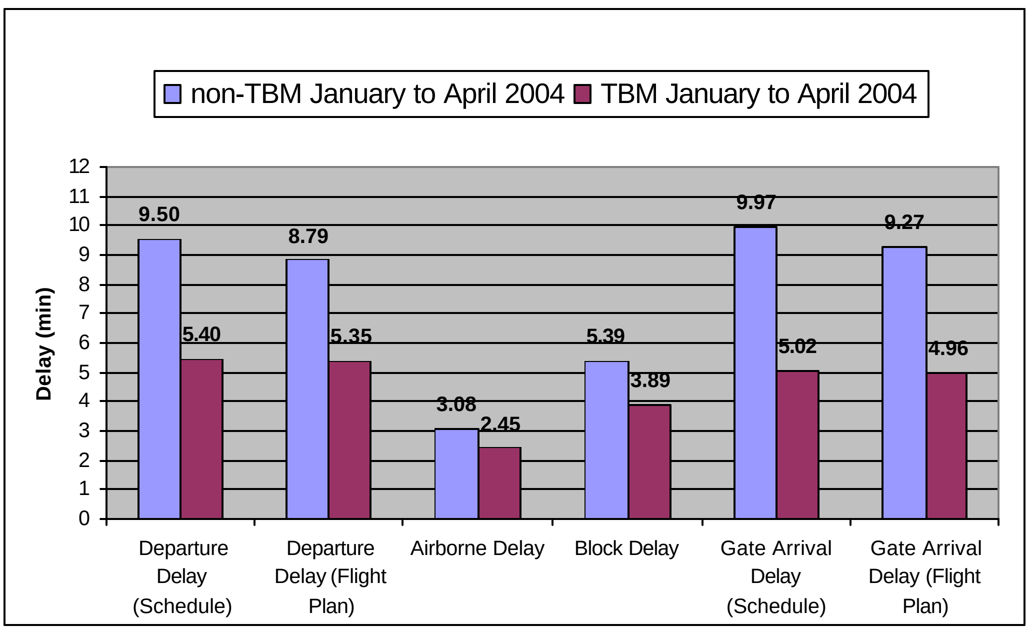

Figure 2-5. ZHU/IAH Internal Departure Delay Comparison

2.1.3.3 Flight distance analysis

In addition to the throughput and internal departures analyses, we also analyzed changes in flight distance for four airspace rings within a radius of 200 nmi outside IAH. We use flight distance as a surrogate for flight time because flight time is highly dependent on wind speed and direction. These rings are:

- Extreme Arc (EA) at 200 nmi
- Outer Arc (OA) at 160 nmi
- Inner Arc (IA) at 100 nmi
- Meter Arc (MA) at 40 nmi

The time range assessed here is from December 2003 to April 2004. During this time period, TBM was used at IAH for 11.1 percent, or 6,181 flights, of all arrivals during two time periods: between 0600 and 1300, and between 1500 and 2000 local time. The total number of non-TBM flights used in this analysis is 49,622. In summary, the Extreme Arc (EA) to Outer Arc (OA) flight distance varied by a small percentage and the change due to TBM is not statistically significant, as shown in Figure 2-6.

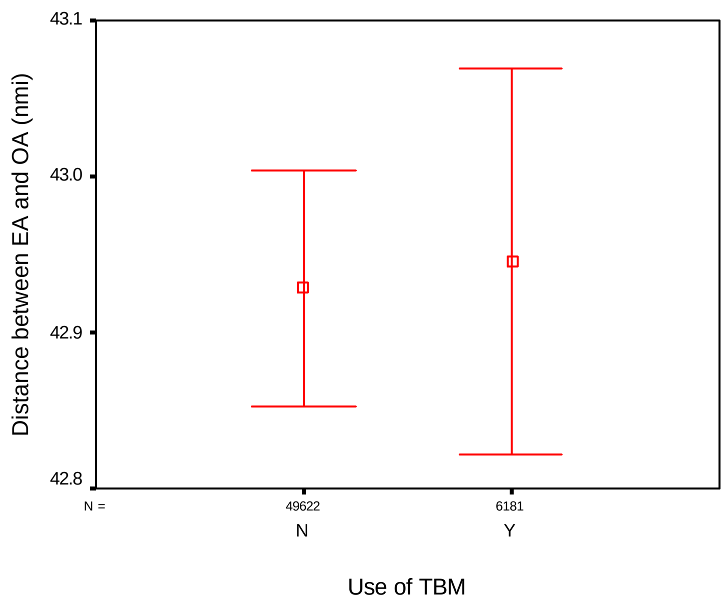

Figure 2-6. ZHU/IAH Flight Distance Comparison, Extreme Arc to Outer Arc

We find statistically significant reductions in flight distance for these three sections between arcs (Outer Arc (OA) to Inner Arc (IA), Inner Arc (IA) to Meter Arc (MA), and Meter Arc (MA) to the runway (RW)). In the rest of this section, we show plots of these results. As shown in Figure 2-7, the average flight distance between the Outer Arc (OA) and the Inner Arc (IA) is 65.4 nmi for periods without TBM, and 63.8 nmi for periods with TBM, a reduction of 1.6 nmi for each flight. This difference represents a reduction of 1,978 travel miles per month.

Next, we examine the flight distance between the Inner Arc (IA), at a radius of 100 nmi from IAH, and the Meter Arc (MA), at a radius of 40 nmi from IAH, as shown in Figure

2-8. The mean flight distance is 64.7 nmi without TBM and 63.6 nmi with TBM, for an improvement of 1.1 nmi per flight. This difference represents a reduction of 1,360 travel miles per month.

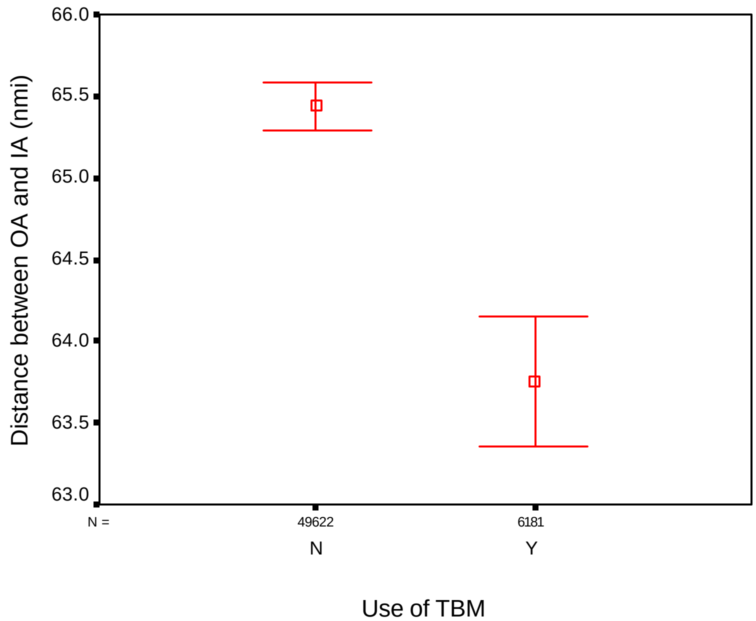

Figure 2-7. ZHU/IAH Flight Distance Comparison, Outer Arc to Inner Arc

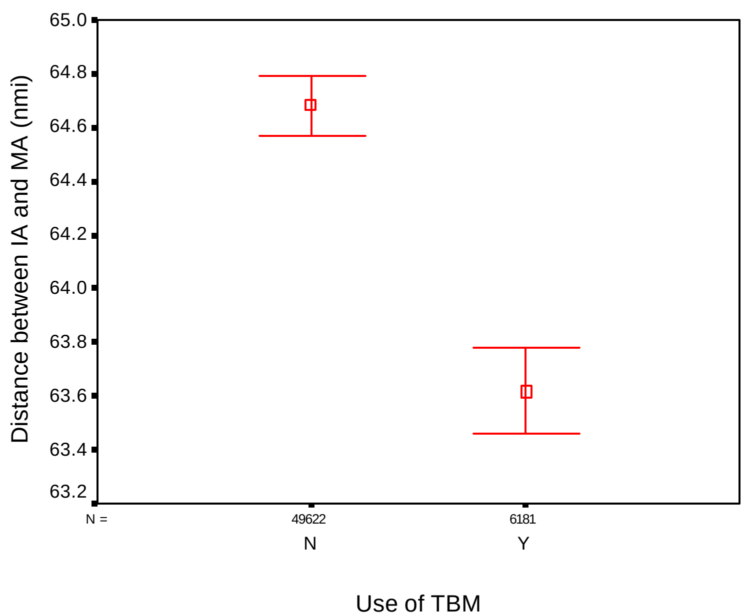

Figure 2-8. ZHU/IAH Flight Distance Comparison, Inner Arc to Meter Arc

We show in Figure 2-9 the flight distance between the Meter Arc (MA), at a radius of 40 nmi from IAH, and the runway. The mean flight distance is 54.9 nmi without TBM and 54.4 nmi with TBM, for an improvement of 0.5 nmi per. This difference represents a reduction of 618 travel miles per month.

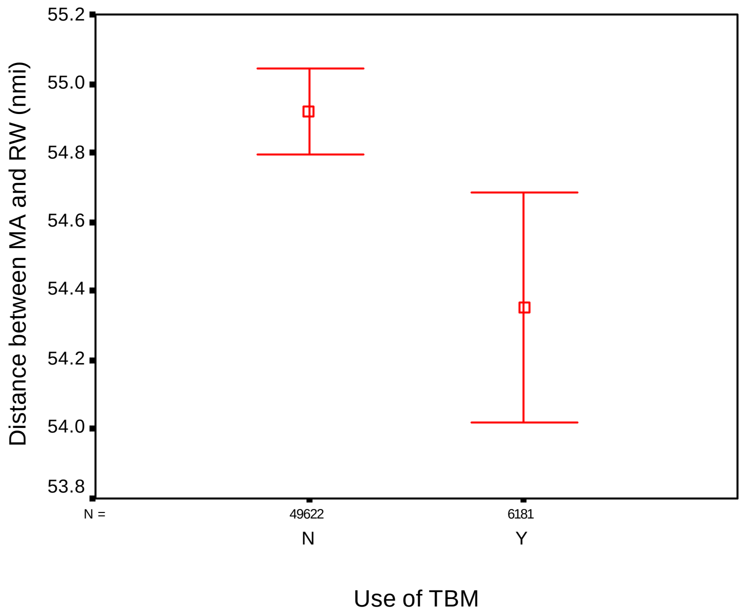

Figure 2-9. ZHU/IAH Flight Distance Comparison, Meter Arc to the Runway

In addition to comparing the mean flight distance between these arcs, we compare their standard deviations, as shown in Figure 2-10. The standard deviations for these three flight distances are smaller for TBM than for non-TBM flights by 3.7 percent for the flight distance between the Outer Arc (OA) and the Inner Arc (IA), by 50.9 percent for the flight distance between the Inner Arc (IA) and the Meter Arc (MA), and by 5.3 percent for the flight distance between the Meter Arc (MA) and the runway (RW)). Once again, these rings are:

- Outer Arc (OA) at 160 nmi
- Inner Arc (IA) at 100 nmi
- Meter Arc (MA) at 40 nmi

2.1.4 TMA at ZLA/LAX

ZLA began daily use of TMA in June of 2001. Initially, ZLA used TMA as a strategic tool for traffic managers, but did not use the list that allows tactical TBM by individual controllers. Personnel at ZLA conducted an operational suitability assessment of TBM with TMA between May and July 2002. They continued additional operational testing in August and September 2002, and began mandatory TBM usage in November 2002 between 0900 and 1200 local time, Monday through Friday. In May 2003, ZLA began to receive an Adjacent Center Data Feed (ACDF) from the ZOA TMA system. ZLA uses this feed to better handle traffic from ZOA airspace including the setting of restrictions between the ARTCCs.

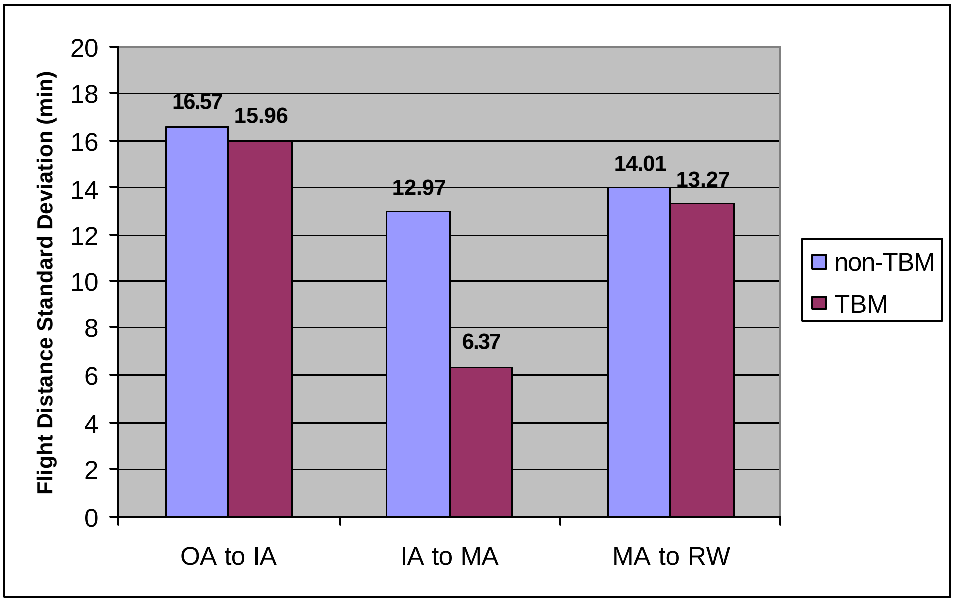

Figure 2-10. ZHU/IAH Arrival Flight Distance Variation

The Free Flight Program Office has reported extensively on the operational benefits of TMA (see, for example, Reference 6). The use of TMA has increased the arrival rate at LAX by about 3 percent, and by an additional 5 percent during IFR conditions when TBM is used. TMA has also helped to reduce the delay for ZLA internal departures bound for LAX.

This year ZLA has gradually increased the frequency and duration of time-based metering. Figure 2-11 illustrates how the total time that ZLA controllers have been using time-based metering has been steadily increasing since the beginning of this year. Figures 2-12 and 2-13 show that the both the average duration of metering sessions and the number of sessions per month have increased.

2.2 New Runway Construction

Since September of 2003, four of the OEP 35 airports have opened new runways. Two of these airports, George Bush Intercontinental Airport in Houston and Orlando International Airport, have closed existing runways at the same time to make improvements on the older runways. Miami International Airport and Denver International Airport, however, have been using the new runways with the existing runways to achieve capacity and throughput increases.

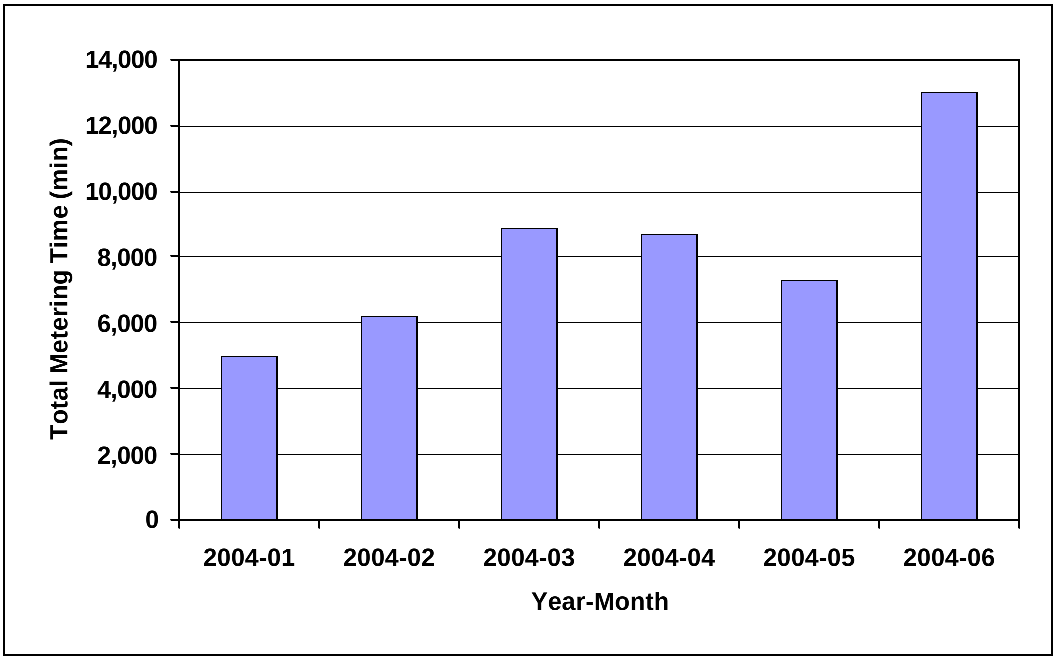

Figure 2-11. ZLA Monthly Time-Based Metering Usage, 2004

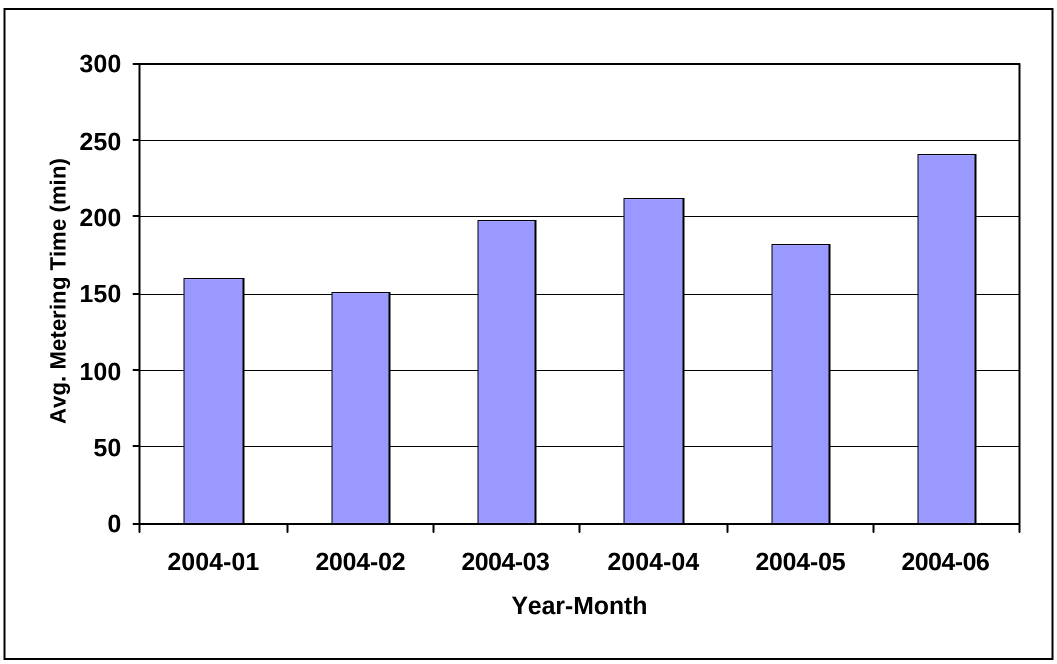

Figure 2-12. ZLA Average Time-Based Metering Session Time

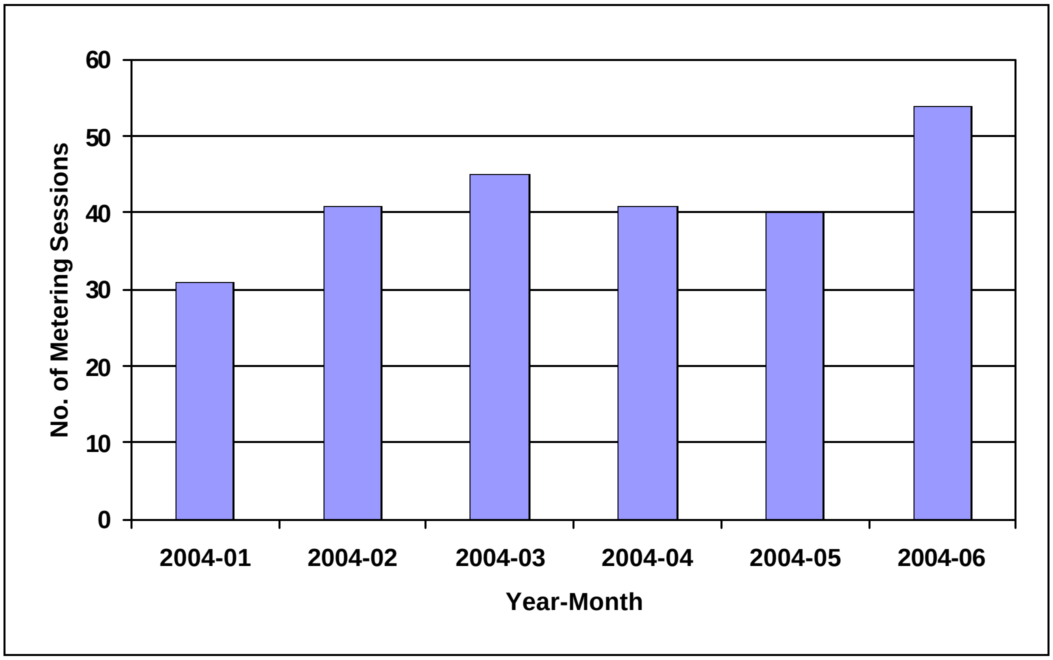

Figure 2-13. ZLA Monthly Time-Based Metering Sessions

2.2.1 Miami International Airport

On September 4, 2003, Miami International Airport (MIA) opened a new runway originally designated 8/26. The new runway is 8,600 feet long, 150 feet wide and is located 800 feet to the north of what was the existing runway 9L/27R. To alleviate confusion, on April 15, 2004, the runways were renamed so that the two parallels on the north side of the airport (including the new runway) are now 8L/26R and 8R/26L. Also, the parallel runway on the south side of the airport, previously 9R/27L, is now 9/27. Figure 2-14 shows the current airport layout including the new runway and the current runway identifications.

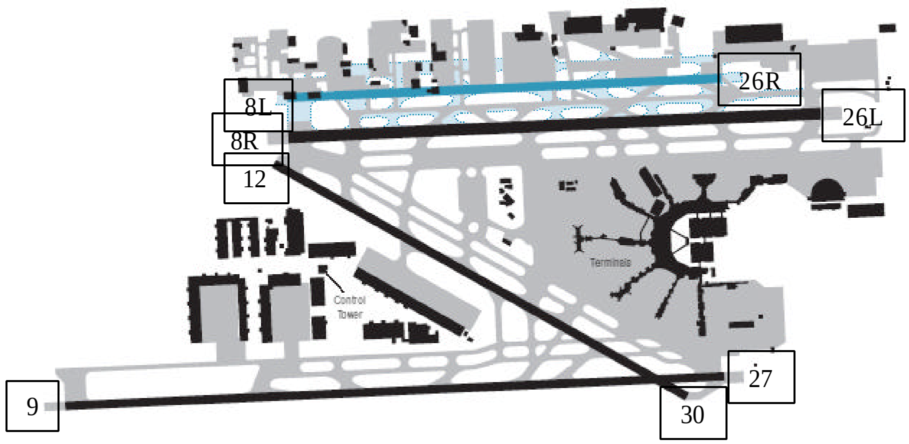

Figure 2-14. MIA Airport Layout

Using data obtained from the Aviation System Performance Metrics (ASPM) web page, we analyzed capacity and throughput data from September 2002 (one year before the new runway became active) to May 2004. Because of its proximity to the existing runway, we do not expect the new runway to have much effect on the efficiency of the airport during Instrument Approach (IA) conditions. However, MIA is in IA conditions approximately only 2.5 percent of the time. We do expect to see improvements in airport throughput during Visual Approach (VA) conditions when MIA is using the new runway.

Before the new runway was in constructed MIA would typically use all three runways for arrivals and departures. They would typically specify an Airport Acceptance Rate (AAR) of 64 aircraft per hour during VA conditions. For MIA, ASPM defines VA conditions as a ceiling of at least 2,000 feet and a visibility of at least five nautical miles. Since the fourth runway has become operational, the AAR has risen to an average of 68, and is often 72 aircraft per hour, when using all four runways. This would appear to be a capacity increase of 12.5 percent, but we need to check that this rate is being utilized. To confirm this, we look at the numbers of arrivals and departures during busy times to see if the actual throughput of the airport has increased. We use the ASPM *Arrivals for Efficiency Computation* and *Departures for Efficiency Computation* fields for our arrival and departure numbers, respectively. To define a busy time for arrivals, we look at 15 minute periods where the arrival demand (as defined in ASPM) is at least as large as the 15 minute AAR. We then separate the time periods by the airport conditions (IA or VA), and the number of runways in use (three or four). During VA conditions, we find that the number of arrivals per 15 minutes increased from 14.0 to 15.3 during busy times (see Figure 2-15). This is an increase in throughput of approximately 9 percent. During IA conditions, the number of arrivals increased from 9.2 to 11.4, or about 24 percent. Both of these results are statistically significant at the 5 percent level.

An analysis of departure throughput at MIA yields slightly different results. There is not an equivalent quantity to AAR to describe the airport's departure capacity, so to define busy times we need to be more creative. We define busy time for departures as those 15 minute periods where departure demand, as defined by ASPM, is in the top 10 percent of those periods where there is any departure demand (i.e., the departure demand is not zero). We find that the 90^{th} percentile of the departure demand when there is demand is 13 aircraft per 15 minutes. Therefore, we looked at departure throughput for the 15 minute periods where the departure demand was at least 13 aircraft. Similar to the VA results, the throughput increased during VA conditions from 13.4 aircraft when three runways are in use to 14.14 aircraft when using four runways (Figure 2-16). This is approximately a 5 percent increase in departure throughput. During IA conditions we do not see a statistically significant difference.

We performed a throughput analysis using rolling 30 minute periods in addition to the above described 15 minute periods, with similar results.

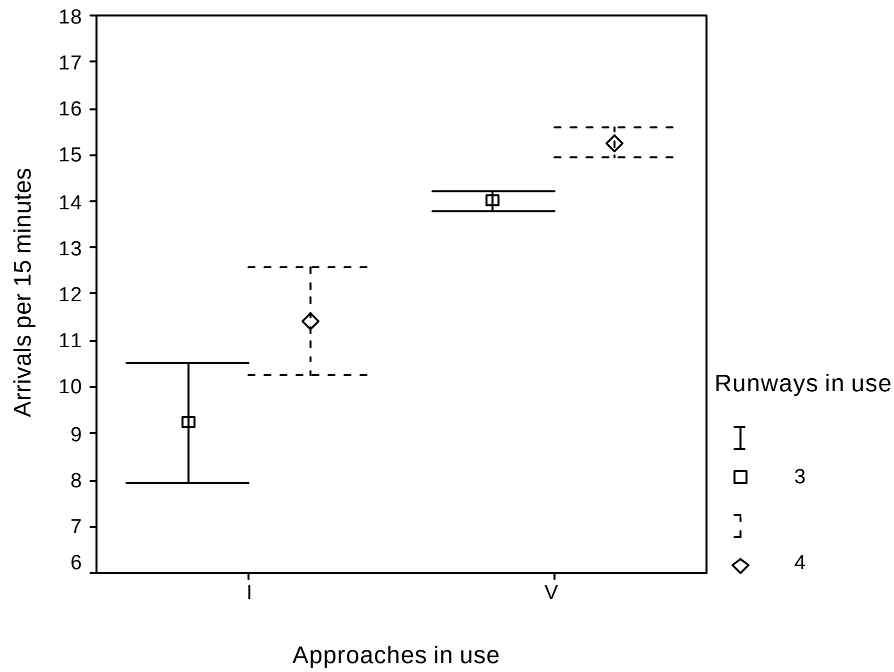

Figure 2-15. MIA arrival throughput comparison. *During IA conditions, the change is not significant. During VA conditions, there is approximately a 9% increase while using the new runway.*

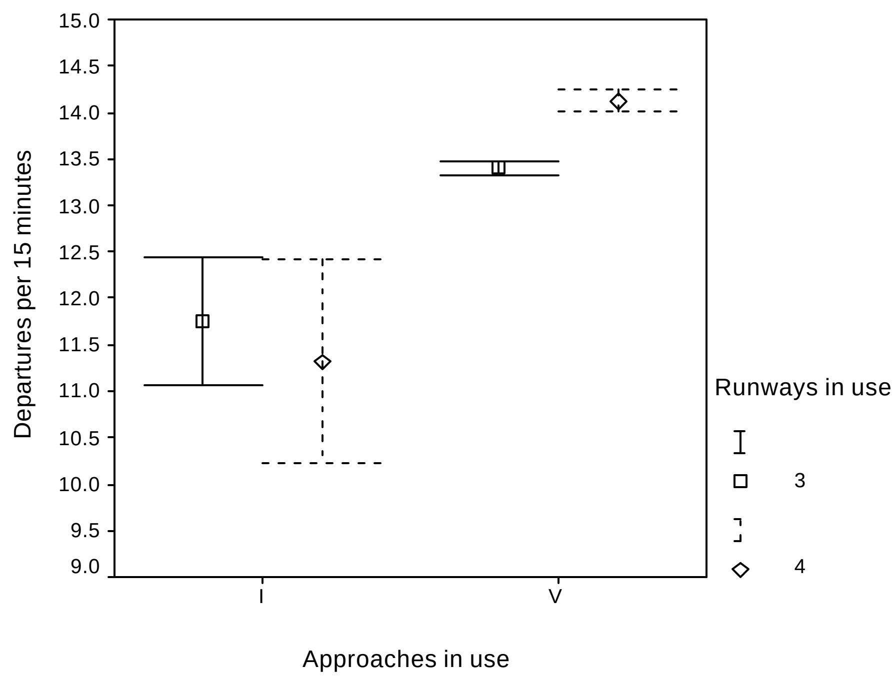

Figure 2-16. MIA departure throughput comparison. *During IA conditions, there is no significant change. During VA conditions, there is approximately a 5% increase.*

2.2.2 Denver International Airport

Also on September 4, 2003, Denver International Airport (DEN) opened a new runway, 16R/34L. This new runway is 16,000 feet long and 200 feet wide. The airport diagram for DEN is shown in Figure 2-17.

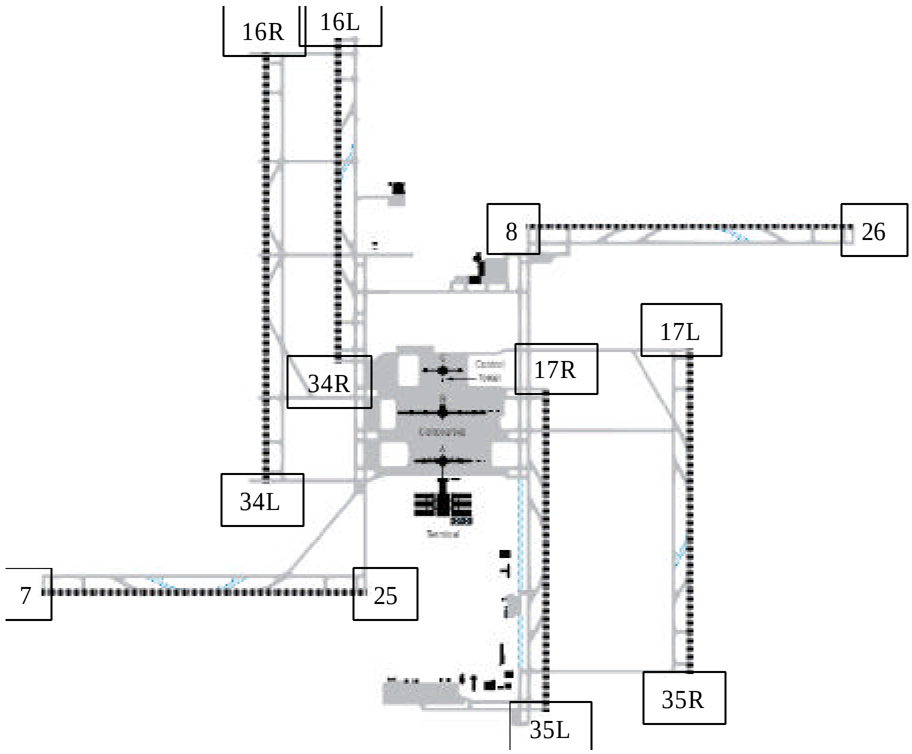

Figure 2-17. DEN Airport Layout

Using data obtained from ASPM from September 2002 (one year before the new runway became active) to May 2004, we analyzed the arrival throughput and the taxi-out times for departing flights. The expected use of the new runway is for departures, which should decrease taxi-out times and increase the arrival throughput since the arrival runways will not be shared with departures as often. A problem in the ASPM data required us to be creative as to ascertaining when the new runway was in use. The new runway is not represented in the ASPM data. Therefore, in the following analyses of arrival throughput, we typically compare periods when the same number of arrival runways have been called, before and after the new runway. Also, for the departure taxi-out times, we simply compare time periods before and after the new runway became operational, as we do not trust the data concerning the number of runways being used for departures.

The first analysis that we performed examined the potential change in throughput during busy times at DEN after the new runway was opened. A complication of this analysis is that the total demand at DEN increased drastically from 2003 to 2004. Therefore, the demand after the runway became operational is higher than before. This could affect the throughput analysis unless accounted for. For example, if we were to use the same definition of 'busy' as we did above for MIA, we would see a throughput increase. However, that increase is offset by the increase of AAR during the busy periods even though the typical AAR during all time periods did not increase. The capacity at DEN is, in general, much higher than the demand. Therefore, to find periods where the demand was greater than the capacity was to pick the periods where the capacity was reduced. For DEN we defined busy as when the arrival demand is 80 percent of the AAR, and the AAR is at least 30 aircraft per 15 minutes, which is the most often called AAR. We also only used VA conditions, which at DEN are defined by ASPM as times when the ceiling is above 2,000 feet and the visibility is at least three nautical miles.

When this filter is applied to the time periods, we find that the number of Efficiency Arrivals increased from 24.1 to 26.3 per 15 minutes when two arrival runways are being used and from 23.1 to 25.9 per 15 minutes when three arrival runways are being used (Figure 2-18). These increases are approximately 9 and 12 percent for two arrival runways and three arrival runways, respectively. However, as mentioned above, we need to see if the demand increased during those periods also. If the demand increases as much as the throughput, than we cannot say that the new runway is the cause of the increase in throughput. In Figure 2-19, we see that the arrival demand per 15 minutes increases from 26.1 to 27.4 while using two arrival runways. This, combined with the increase in throughput, suggests that we can attribute approximately one more aircraft per 15 minute period in throughput to the new runway (2.21 increase in throughput minus 1.26 increase in demand) while using two arrival runways. For times when three arrival runways are in use, the arrival demand difference before and after the new runway was opened is not statistically significant. Therefore, the entire increase in throughput can be attributed to the new runway.

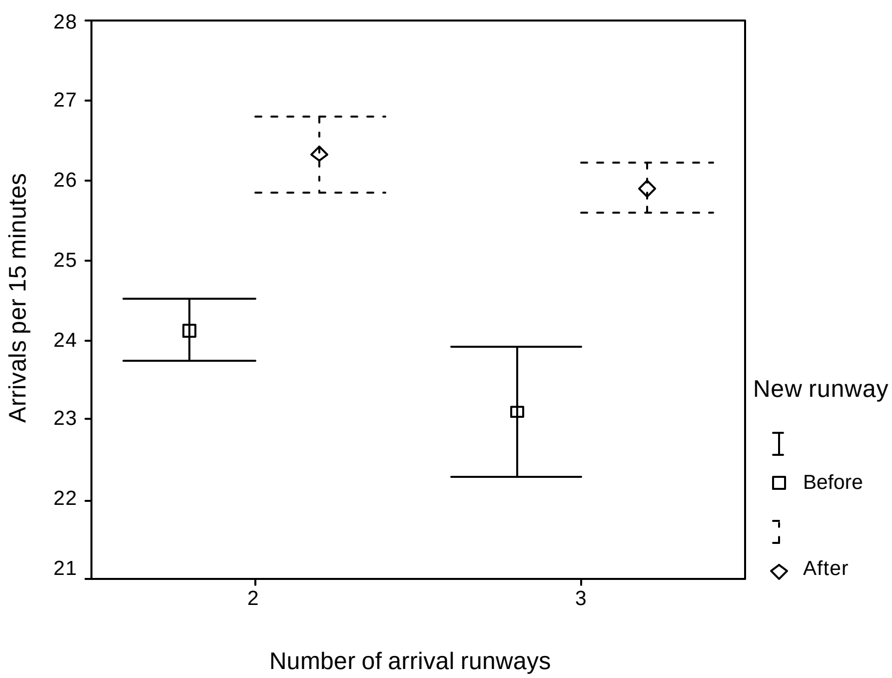

Figure 2-18. DEN arrival throughput comparison. *Arrival throughput during busy times has increased after the introduction of the new runway.*

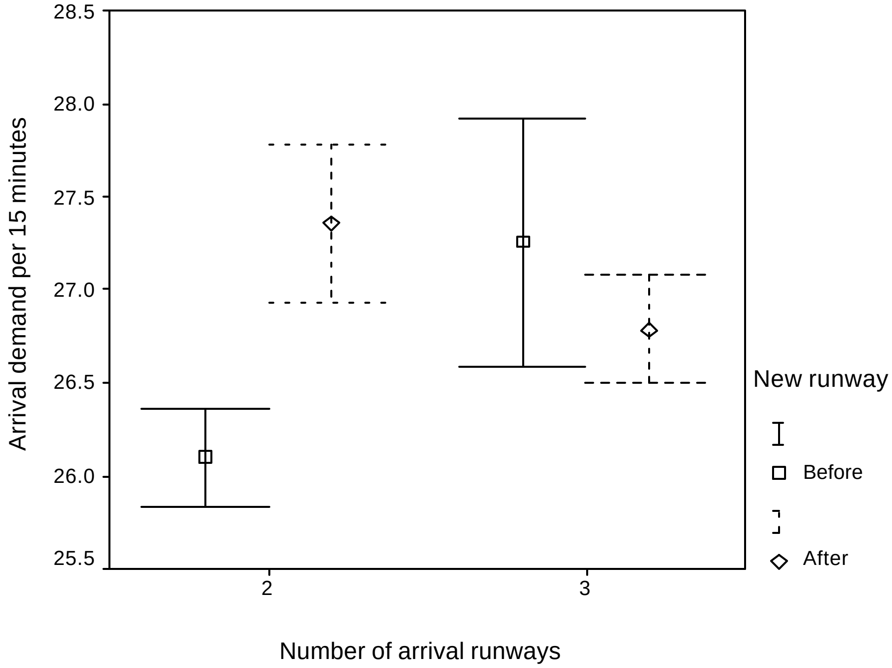

Figure 2-19. DEN arrival demand comparison. *The change in arrival demand is insignificant when there are three arrival runways and smaller than the change in throughput when there are two arrival runways.*

To look at the effect that the new runway has on departures at DEN, we analyzed, flight by flight, the taxi-out times of DEN departures. Once again, we are concerned about busy times. If we were to look at all times, we would see a taxi-out time increase since the new runway is further from the terminals than the other runway used for departures. Therefore, we look at busy times to see if the new runway has an affect only when there may be delays during the taxi-out process. We only look at flights that have Out-Off-On-In (OOOI) data. Approximately 60 percent of all traffic at DEN supplies OOOI data to ASPM. We define busy times for departures similarly to how we defined them for MIA above. The 90th percentile of departure demand when there was departure demand is 21 flights per 15 minutes. Therefore, we looked at flights that departed during time periods where the departure demand (including non-OOOI flights) was at least 21 aircraft. We see that the taxi-out time decreased from 17.7 minutes to 17.3 minutes after the new runway opened (Figure 2-20). This is a decrease of approximately 23 seconds per flight.

2.2.3 Orlando International Airport

In December of 2003, Orlando International Airport (MCO) opened a new runway 17L/35R. The new runway is 9,000 feet long and 150 feet wide and is located 4,300 feet to the east of the existing runway 17R/35L. However, MCO has temporarily closed runway 17R/35L for improvements. The new runway is similar enough to the closed existing runway in terms of length, taxi-way configuration, and ability to accommodate simultaneous independent instrument approaches that we do not expect to see any capacity or efficiency gains until the previously existing runway is back in service.

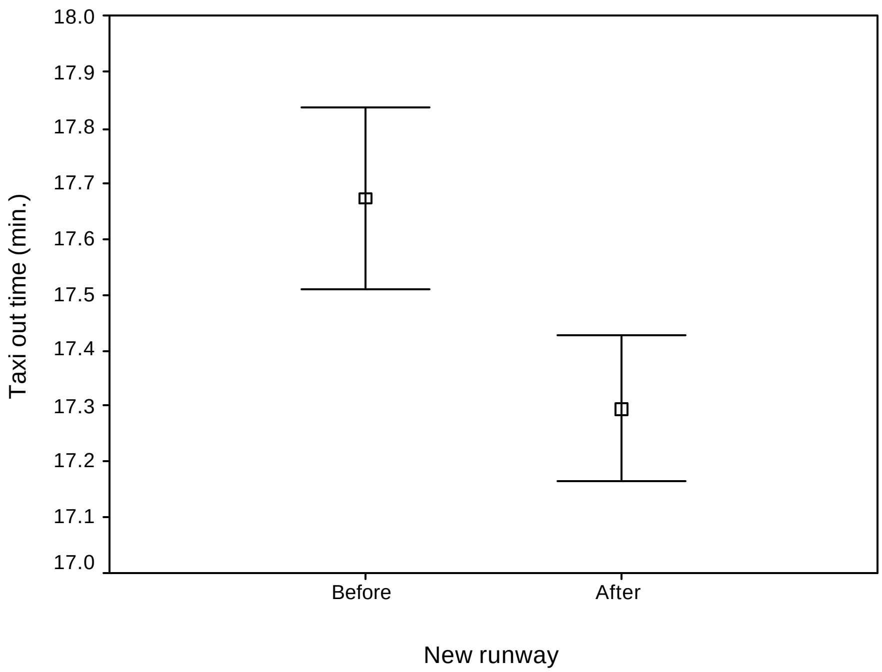

Figure 2-20. DEN taxi-out time comparison. *During busy periods, the taxi-out time has decreased by approximately 23 seconds.*

2.2.4 George Bush Intercontinental Airport

In December of 2003, George Bush Intercontinental Airport (IAH) opened a new runway designated 8L/26R. The new runway is 9,000 feet long and 150 feet wide. This runway allowed IAH the opportunity to close runway 8R/26L for construction without compromising airport capacity. Because of the simultaneous taxi-way construction, new runway, and start of use of TMA time-based metering, we are unable to separate the impact of the new runway at this time. A discussion of the combined impact of these changes was presented in Section 2.1.3.

2.3 Surface Movement Coordination

New tools for airport surface traffic management will provide airport personnel the capability to predict, plan, and advise surface aircraft movement. Animated airport surface displays for all vehicles on the ground will display information in real time to all parties of interest. Displays of aggregate traffic flows on the surface will help project demand and balance runways and arrival and departure flows more efficiently. In addition, these new tools will be shared with flight operations centers to provide a common situational awareness and collaborative decision making and allow all parties to anticipate and plan for impacts in advance.

In this section, we present analyses of surface surveillance data shared with airlines to promote surface efficiency at Detroit Wayne County Metropolitan Airport (DTW), Dallas Fort Worth International Airport (DFW), and Memphis International Airport (MEM). ATO Technology Development supported this research.

2.3.1 Shared Surface Surveillance Data at DTW

2.3.1.1 System Description and History

The Airport Target Identification System (ATIDS) is a prototype multilateration system that provides accurate position information of transponder-equipped aircraft operating on the airport surface. A government/industry partnership between the FAA, NASA, Sensis Corporation, and the DTW airport authority installed ATIDS as a research and development project in 1999.

The DTW ATIDS consists of nine remote unit sensors providing surface surveillance coverage. In February 2002, FAA ATO Technology Development (formerly the Safe Flight 21 and Surface Technology Assessment Team) installed communications and computer equipment, including three displays within the Northwest Airlines (NWA) ramp tower and displays at the NWA System Operations Control (SOC) Center in Minneapolis, MN. The purpose of this effort was to probe the benefits of distributing real-time, filtered surveillance data to an airport user. The system provides NWA with aircraft position and flight call sign information. The FAA also prepared a data sharing Memorandum of Agreement with NWA that formally launched the demonstration. During the subsequent one-year period, anecdotal evidence indicated that the sharing of surface surveillance data had a positive impact on efficiency and safety. To further explore these benefits, the FAA established a metrics working group in February 2003.

2.3.1.2 Metrics Output and Results

One of the first challenges identified within the metrics working group was the lack of a baseline period. DTW airport and NWA operations underwent several changes concurrent with availability of shared ATIDS data at the ramp tower and at the NWA SOC in Minneapolis. In December 2001, DTW finished a new runway and associated taxiways. In the spring of 2002, NWA moved into a new terminal that included a ramp control tower and ATIDS. Each of the structural changes resulted in significant changes to taxi flows and ramp movement. In addition, with the change of terminals, NWA gained control of a significant portion of the ground movement area for the first time. Because of the large changes in airport and airline infrastructure during this period, the working group determined that straightforward analyses of taxi times before and after ATIDS use would lead to flawed results.

Another challenge involves the number of locations and individuals using ATIDS, and the fact that easy access to the shared data has become second nature. As a result, it is difficult to document and summarize each time the system is used.

Subsequently, most of the evidence for each of the benefits relies on examining specific instances of savings because of data sharing after ATIDS installation. We then use data and expert opinion to determine the frequency of such occurrences and, where possible, extrapolate to estimate a yearly benefit.

In the following, we outline analyses done in support of this effort.

More efficient movement in the ramp area

Problem: Due to the lack of complete real-time surveillance in the ramp control tower, ramp controllers have limited ability to determine location, order, and status of flights outside ramp tower visibility and/or control. Limited ability to anticipate timing and order of arrivals into the ramp area and monitor departure runway queues results in inefficient movement in the ramp area due to inbound/outbound flow conflicts.

Capability/Direct Impact: Improved real-time surveillance in the ramp control tower provides an increased ability to anticipate the location and order of arrivals and an increased ability to monitor runway departure queues.

Outcome/Benefit: This information assists the controller in decreasing the number of conflicts between the inbound and outbound flows resulting in more efficient movement in the ramp area. More efficient movement in the ramp area should reduce taxi times for many flights. Reduction in taxi time translates to savings in aircraft direct operating costs (fuel, crew), passenger and crew missed connections, and customer ill will.

Evidence: This is one of the few listed benefits that should occur on a daily basis. The preferred method for determining the impact would be to examine the mean and variance of taxi times before and after implementation. While a source for taxi times is readily available, the group determined that a straightforward analysis of taxi times before and after ATIDS use would lead to flawed results due to large changes in airport infrastructure during the same period.

To estimate the impact of ATIDS on day-to-day operations, we asked the ramp controllers to document specific instances where the ATIDS display saved taxi-time. In this log, controllers recorded taxiways used, actual taxi times, how or if ATIDS assisted in the taxi process, and estimation of taxi time saved due to the tool.

The majority of savings day-to-day occurred during times when controllers must manage both arrival and departure flows. The NWA ramp tower manages over 80 percent of the DTW traffic. The ramp tower traffic load consists of NWA aircraft (about 60 percent), and aircraft from the NWA partners Mesaba Airlines and Pinnacle Airlines.

Controllers find that they can save approximately 3 minutes of outbound taxi time by allowing a flight to be pushed straight back from the gate, as opposed to making a turn during the push-back. However, a straight push-back blocks a large section of the ramp area and may increase taxi time for multiple inbound aircraft. Without information on location, order, and timing of inbounds, controllers hesitate to push straight back in order to avoid conflicts and inbound delays. With ATIDS, controllers now have enough information on arrivals to make better judgments on when, or when not to allow a straight push-back on a departure. Ramp controllers estimate that this saves approximately 45 minutes of taxi time per arrival/departure bank, or about 23 seconds per aircraft. These savings are a combination of taxi-out time due to straight push-backs, and taxi-in time due to avoiding inbound delays by giving some outbounds turned push-backs. Given that there are 9 banks a day, and 365 days in a year, we estimate a yearly taxi time savings of 2,464 hours. This savings is split between NWA flights (~60 percent) and partner flights from Mesaba Airlines and Pinnacle Airlines.

More efficient handling during irregular operations

Problem: Irregular operations include times of severe snow and ice, fog, and heavy crosswinds. On average, NWA manages 35 of these events a year at DTW. Due to the lack of complete real-time surveillance in the ramp control tower, ramp controllers have limited ability to monitor runway queues and limited visibility during irregular operations, which leads to inefficiencies in the ramp area. Lack of real-time surface surveillance at the SOC limits the ability of the SOC to monitor surface information, resulting in more cancellations than necessary.

Capability/Direct Impact: Improved real-time surveillance in the ramp control tower provides increased visibility during irregular operations (like deicing) and allows monitoring of departure and pad queue lengths. Real-time surveillance of queue lengths and aircraft locations by the SOC, allows more precise calculations of the number of necessary cancellations during some irregular operations.

Outcome/Benefit: These impacts allow the ramp and the SOC to provide a more efficient flow during irregular operations. More efficient irregular operations result in reductions in taxi time and cancellations during those times. Reduction in taxi time translates into savings in aircraft direct operating costs (fuel, crew), passenger and crew missed connections, and customer ill will. Reduction in cancellations translates to savings in airline interrupted trip expenses, passenger and crew missed connections, and customer ill will.

Evidence: Because two storms are never exactly the same, it is difficult to determine if a tool has had a positive impact during severe weather by examining results before and after implementation. At DTW, the difficulty in determining a proper baseline is compounded by the previously mentioned changes in infrastructure during ATIDS installation. This does not mean that we cannot estimate current benefits. One of the most beneficial changes occurred due to analysis of data during a deicing event. Because the effects of this change in operations occurred primarily because of post-event analysis, we describe the details and evidence under the **Resolution of systematic surface flow problems** benefit section. Beyond this systematic change, NWA also described specific instances of severe weather, during which real-time surveillance saved either time or cancellations.

DTW experiences extremely heavy fog about 4 to 5 times a year. The fog generally occurs during the first two arrival banks. Ramp control estimates that without reliable surface surveillance, taxi time for arrivals would increase by at least 4 min per aircraft and communication time would double. Using the average bank size of 60 arrivals, we estimate a savings of approximately 32 hours of taxi time a year due to the ATIDS display.

On April 4, 2003 long periods of freezing rain at DTW forced runway closures. The NWA SOC copes with such an occurrence by delaying and canceling flights. The SOC first does a simple calculation involving the scheduled departures and the current departure and deicing rates to determine an optimal tradeoff between delays and cancellations. They then choose specific flights based on crew and aircraft patterns, maintenance requirements, number of passengers, connections, etc. When the SOC checked the position of flights on the surface, they found that some of the flights to be canceled were either already deiced, or were near the front of the deicing queue. They recognized that sending these flights back to the gate would waste deicing fluid, taxi fuel, and slots in the departure queue. They decided to cancel only the flights that were close to the gates and let the other flights depart as scheduled. They continued to closely monitor flight locations and deicing speed through the ATIDS display and found that pad throughput exceeded expectations (requiring fewer cancellations). The NWA SOC estimates that they avoided 10 to 12 cancellations that night and another 10 to 12 cancellations the next day that would have occurred due to balancing of the fleet. That is a total of 20 to 24 cancellations avoided during this one event. This is an example of unusually bad weather that happens about once a year during the deice season.

The SOC hopes to use the system in the future to identify potential logjams at the deice pads in real time. With this information they will decide whether or not to hold planes at the gate instead of on the tarmac, and proactively decide on canceling of flights. This should help the airline save some fuel during taxi and deicing and allow people to wait inside the terminal (as opposed to on the plane) during extended delays.

Fewer calls between ramp, SOC, pilots, and ATC

Problem: Due to the lack of complete real-time surveillance in the ramp control tower, ramp controllers have limited ability to determine location, order, and status of flights outside ramp tower visibility/control and during times of reduced visibility. To acquire enough information to efficiently manage ramp traffic, the ramp must contact each flight multiple times. The ramp and ATC towers must also respond to telephone calls from the SOC requesting critical flight location, runway configuration/status and emergency information. Excessive phone or radio traffic may result in missed calls and confusion between parties.

Capability/Direct Impact: Improving real-time surveillance in the ramp control tower provides increased awareness of the airport surface, including location, order, and status of incoming and outgoing flights. Real-time surveillance in the SOC provides critical flight location, runway configuration/status, and emergency information without ramp control or ATC communication.

Outcome/Benefit: With improved information, the ramp controllers do not need to radio the pilots as often during an operation. The shared view in Minneapolis reduces the need for the SOC to call the ramp control tower or ATC. Reduction in unnecessary communication time on both radio and telephone allows ramp and ATC more time to focus on the safe and efficient flow of surface traffic.Evidence: NWA ramp controllers, the NWA SOC analysts, and ATC ramp controllers all claim this benefit is realized on a daily basis**.** Below we examine the magnitude of the decrease in communication from the perspectives of the ramp and the SOC. The values were determined by user input based on daily interaction with ATIDS over several months.

With ATIDS, NWA ramp controllers contact each inbound flight from one to four times and each outbound flight twice. When ATIDS is not available, the ramp has to contact each inbound flight between one and two more times to verify position, and there are approximately 10-20 percent more calls to outbound flights. Assuming equal numbers of arrivals and departures, this represents a 27 percent decrease in total communication time.

To put this change in perspective, we examine the amount of time spent on the radio compared to the total available time during peak traffic loads. During a typical bank (local peak in arrival and departure traffic) the arrival and departure rates can reach 60 aircraft per hour. The typical communication time between ramp and pilot is approximately 10 seconds. Using this information and the number of calls from above, we estimate that when ATIDS is not available, controllers spend 26 percent of the available time on the radio; with ATIDS they spend 19 percent of the available time. This decrease in radio time per flight allows the controller more time to focus on safe and efficient flow during these peak loads.

The SOC searches for the location of an aircraft at DTW at least six times a day. Before ATIDS, the SOC had three possible means of acquiring this information. They either called the NWA ramp tower, called ATC, or had a dispatcher contact the plane and wait for a response. The reliability of information from the ramp or ATC was sometimes hampered by workload or reduced visibility. With the shared data, the SOC estimates that it has reduced this unnecessary communication by 75 percent, reducing the number of calls from six to one or two a day.

More efficient response to airport/airspace conditions and emergencies

Problem: Due to the lack of real-time surveillance, the SOC has limited ability to determine the current runway configuration, runway status, or surface emergency status without communication from the ramp tower. Delay in the transmission of this information can lead to inefficient responses to airport and airspace conditions, or emergencies.

Capability/Direct Impact: Real-time surveillance at the SOC provides increased awareness of the airport surface, including the ability to determine runway configuration, runway status, and emergency status.

Outcome/Benefit: The increase in information should lead to more efficient responses to changes in airport/airspace conditions and emergencies. More efficient responses from the SOC should decrease delay for flights arriving or departing from DTW, or at other airports that will be affected by these changes, and reduce the number of unnecessary diversions. Reduction in delay translates to savings in aircraft direct operating costs, passenger and crew missed connections, and customer ill will. Reduction in diversions translates to savings in airline interrupted trip expenses, passenger and crew missed connections, and customer ill will.

Evidence: We provide two examples of situations that correspond to this outcome, and comment on their occurrence.

Example 1: February 25, 2003 – It was known that Flight 68 might have a potential problem on landing and emergency equipment was dispatched. Managers and dispatchers in the SOC prepared to divert or hold traffic to DTW in the event of an incident. Before ATIDS, rapid communication with the ramp tower was necessary for the SOC to devise a fleet-wide response. In similar past situations, this communication was delayed because ramp control was busy with the immediate problem on the surface. The SOC saw that Flight 68 successfully landed and rolled off the runway using the ATIDS display.

The SOC estimates situations like the one stated above occur approximately three to four times a month. However, a potential emergency that closes down a runway has not occurred in the past several years, so it would be difficult to determine a yearly benefit. If an event did occur, the SOC would be better prepared.

Example 2: August 23, 2003 – ATC stopped Flight 1237 on a taxiway with a 30-minute ground delay because of en route congestion. NWA dispatch (located in the SOC) saw that the flight was stopped on the ATIDS display and contacted ATC for a re-route. Subsequently, the aircraft got an immediate clearance to depart. The re-routed flight was 10 minutes longer than the original flight plan, however, it saved 30 minutes of ground delay, resulting in a savings of 20 minutes.

The SOC estimates that dispatchers are now responding to similar situations one to two times a day. Historically, ATC grants approximately half of the SOC re-route requests. Using 20 minutes as an average savings time, we estimate that NWA flights save approximately 89 hours a year with this benefit.

Resolution of systematic surface flow problems

<u>Problem:</u> Due to the lack of archived surface surveillance tracks at the SOC, analysts must rely on coarse information to determine systematic surface flow problems. (Inefficient deicing procedures, delays caused by inefficient transmission of weight and balance information, and bottlenecks at particular surface locations are all examples of systematic problems.)

<u>Capability/Direct Impact</u>: Post-audit surface surveillance tracks at the SOC provide increased ability to find and analyze systematic surface flow problems.

<u>Outcome/Benefit</u>: Analysis of surface track data should allow the SOC to take steps to resolve the flow problem. Resolutions of systematic surface flow problems should result in reductions in taxi delays. Reduction in delays translates to savings in aircraft direct operating costs (fuel, crew), passenger and crew missed connections, and customer ill will.

<u>Evidence</u>: This benefit is a catchall for the impact of new post-operation analyses made possible through the use of surface surveillance tracks. We do not claim that ATIDS can analyze and resolve surface flow problems; it only provides a better source of data. Any benefit is therefore due to changes made by operators in response to analyses performed using this data. Below, we outline an example of how NWA completely changed their deicing procedures because of evidence gathered using ATIDS.

Example: On January 2, 2003 a moderate snowstorm hit DTW. This was the first severe weather event where ATIDS was fully operating in real-time at the NWA SOC. During the storm, analysts and managers examined the ATIDS display and visually noticed some of the inefficiencies in the deicing operation. Specifically, they noticed that one of their operating ice pads had a large queue, while the other one was virtually empty. In follow-up analyses, NWA analysts quantified some of these inefficiencies. They determined that there were 90 hours of delay that could have been prevented.

Using this information, NWA and local ATC at DTW changed the way they work together during deicing events. NWA also made many procedural changes including moving the deicing coordinator from a truck on the surface to the ramp tower, so that he could view traffic on ATIDS display. NWA believes that such changes would have been much more difficult to detect and analyze without the display. Also, part of the change in operations (estimated 30 percent-50 percent) depends on real-time monitoring of traffic and deicing flows with the ATIDS display. The NWA SOC determined that they handle approximately 16 similar deicing events at DTW during a season. They estimate that monitoring flows during deicing events will save them 432-720 hours of delay a year.

2.3.2 Shared Surface Surveillance Data at DFW

2.3.2.1 System Description and History

As part of the Runway Incursion Reduction Program (RIRP), the FAA installed an Airport Surface Detection Equipment - Model X (ASDE-X) multilateration (MLAT) system on the east side of Dallas-Fort Worth International Airport (DFW). NASA later installed ASDE-X on the west side as part of a data collection program. The Airport has been making these systems permanent in order to satisfy a commitment made to the FAA for mitigation of visibility restrictions to the Center Airport Traffic Control Tower caused by airport development. The ASDE-X provides both surveillance and identification of all transponder-equipped aircraft and vehicles on the airport surface. The DFW ASDE-X MLAT installation will demonstrate the performance and effectiveness of current multilateration surveillance technology, and also serve as a long-term test bed for the integration and evaluation of other runway safety technologies.

In March 2002, the FAA gained the support of American Airlines, Delta Air Lines, and the DFW Airport Board to determine potential benefits in efficiency and safety associated with surface surveillance data sharing. The FAA agreed to provide a real-time MLAT data feed to the participants along with the necessary equipment, communications links, and training. The Safe Flight 21 and Surface Technology Assessment Team also entered into data sharing Memoranda of Agreement with the participating outside interests through September 2004. The prototype MLAT data sharing began in May 2002 and became available for consistent use in November 2003.

Surface surveillance displays are currently located in the American Airlines SOC, the American Airlines ramp tower, the American Airlines Headquarters, the Delta Air Lines ramp tower, the DFW Airport Board operation center, NASA Ames, and the DFW Airport Emergency Operations Center (EOC). A display is also planned for the Delta Air Lines Headquarters. Displays for FAA users in the DFW ATC control towers, and in the TRACON will be available when the ASDE-X system is commissioned in 2005.

More efficient movement in the ramp area

Problem: Due to the lack of real-time surveillance, airline ramp controllers have limited ability to determine location, order, and status of inbound and outbound flights. This limited ability results in inefficient ramp movement.

Capability/Direct Impact: Real-time surface and terminal surveillance provides ramp controllers an increased ability to anticipate the ETA and order of arrivals and an increased ability to monitor runway departure queues.

Outcome/Benefit: These impacts should aid the ramp controller in proactively controlling gate out times and deconflicting multiple inbound and outbound flows resulting in less delays and more efficient aircraft movement in the ramp area. More efficient aircraft movement in the ramp area should reduce taxi time for many flights.

Evidence: The Delta tower started receiving a multilateration surface surveillance feed in April 2003. The system was made stable for consistent use by November 2003. We examine taxi times before and after implementation to try and gauge an impact of this new information.

We use Airline Service Quality Performance (ASQP) OOOI (Out Off On In) data, runway configuration data, and weather data all recorded on the Airport System Performance Metrics (ASPM) database. While we are interested in all the flights controlled by the Delta ramp tower (all Terminal E flights except Northwest Airlines), we only have consistent ASQP data from Delta flights.

The baseline period data set contains dates between 1 December 2002 and 31 March 2003. The post-implementation data set includes data from 1 December 2003 through 31 March 2004. In November 2002, American Airlines (the dominant carrier at DFW) changed their number of arrival and departure peaks. This dramatically decreased average taxi times for all carriers at DFW. Since we thought that the effect of this depeaking operation would have dominated any change seen in the taxi data, we chose to only examine times after this event.

ASPM also records runways in use for each fifteen-minute period in a day. The recorded data lists each of the open runways, but DFW primarily operates in one of two runway configuration modes: North flow and South flow. During a particular flow, most of the flights arrive and depart facing the direction of the flow. Since Delta (Terminal E) is located on the South side of the airport, departures during a South flow must taxi all the way to north end of the airport to takeoff. Consequently, we expect that taxi-out times during a South flow will be longer than during a North flow.

In the analysis we separate flights into North or South flow operations. For the time periods examined, DFW operated in South flow 57 percent of the time and in a North flow 43 percent of the time.

The last factor we consider is the weather. ASPM records airport surface visibility and ceiling. From these variables, there is an algorithm based on facility input that divides the weather into Instrument Approach conditions (IA) or Visual Approach conditions (VA). To qualify for VA, the visibility must be greater than five miles, and the ceiling must be greater than 3500 feet. While this is a gross simplification of weather effects, this division should help isolate periods of relatively good and bad weather. We expect that average taxi times will increase during bad weather.

For the time periods examined, DFW operated in VA conditions 74 percent of the time and in IA conditions 26 percent of the time.

Figure 2-21 displays the average taxi-out times for Delta aircraft during VA condition operations before and after implementation of surface surveillance. The graph shows separate measures for South Flow and North Flow. The annotations on the graph are the mean values. The error bars represent the 95 percent confidence interval around the mean. In general, if the confidence intervals for two averages do not overlap, the difference between the two means is significant to the 95 percent level. We also checked the significance of the difference in the means using an independent T-test. All further results are significant at the 95 percent level unless otherwise noted.

As expected, the average taxi-out time during South flow is larger than during North flow (approximately 2 minutes longer). The mean taxi-out after surveillance is approximately 0.5 minutes less than before surveillance in both configurations. This may not seem dramatic, but consider the changes in mean taxi-out for the other ASQP flights at DFW in the same period (Figure 2-22). During a time when the mean taxi-out times for everyone (except for Delta) increased by about one minute, Delta taxi-out times decreased by 30 seconds. We assume taxi-out time increased for most of the airport because of an increase in traffic at DFW by 9 percent during the period, not because of decreases in Delta taxi-out time.

In Figures 2-23 and 2-24 we show similar graphs for IA conditions. Here the results are not as clear. For South flow, the Delta taxi-out times before and after surveillance do not change significantly. For North flow there is a dramatic decrease of 2.3 minutes after surveillance; however, all the ACARS flights at DFW seem to have the same trend (Figure 2-24). The reason for this variation may lie in the fact that all IA condition weather is not equal. For example, there may have been more severe ice storms in one winter compared to the other. Our analysis would not capture differences in weather severity.

Table 2-3 presents a summary of the differences seen in the graphs.

We also examined taxi-in results for the same time period. We saw no significant evidence of surface surveillance impact on taxi-in times. One reason for this lack of change may be that On and In times from the CTAS display are sufficient to optimize most of the taxi-in flow. However, since there are usually inbound and outbound flights operating simultaneously at Terminal E, a reduction in taxi-out time implies better coordination between inbound/outbound flows. The taxi-out decrease in VA conditions would be less likely without a good understanding of inbound positions from CTAS or surface surveillance.

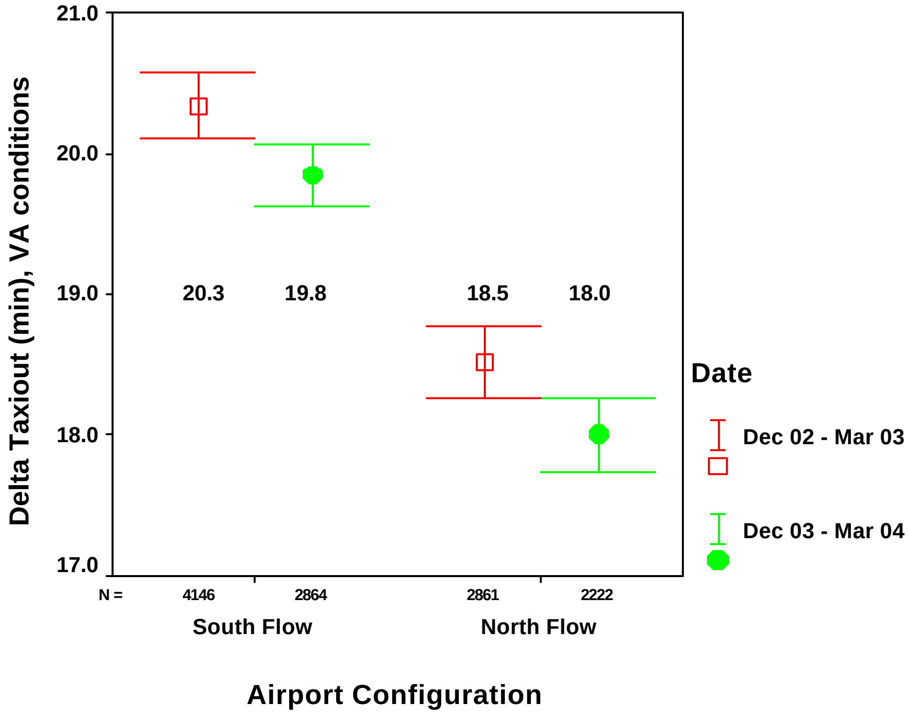

Figure 2-21. Taxi-out times at DFW before and after surveillance in VA conditions, Delta Air Lines

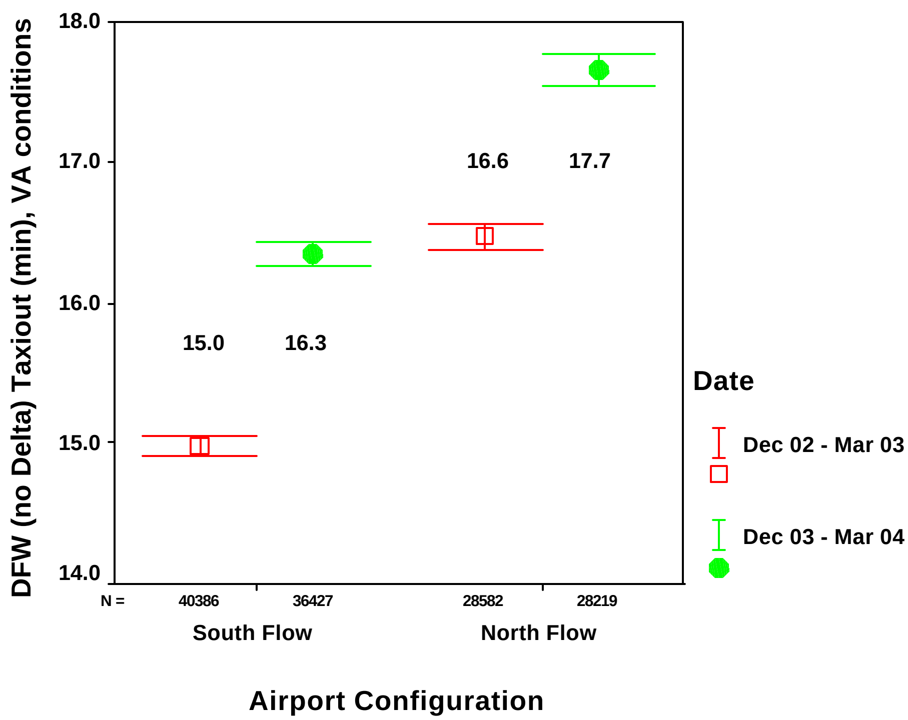

Figure 2-22. Taxi-out times at DFW before and after surveillance in VA conditions, All Other Airlines

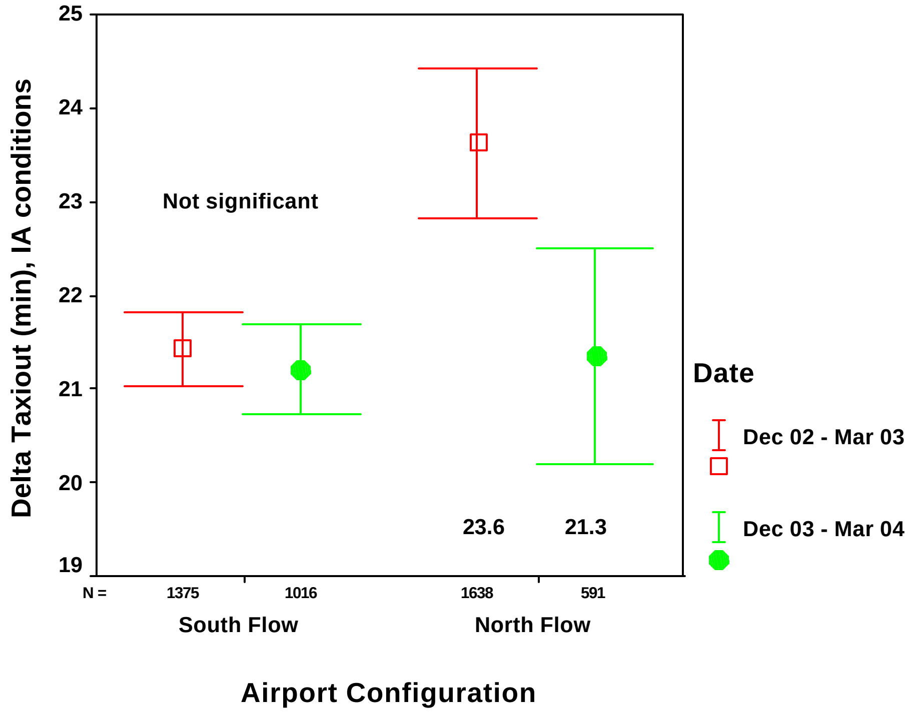

Figure 2-23. Taxi-out times at DFW before and after surveillance in IA conditions, Delta Air Lines

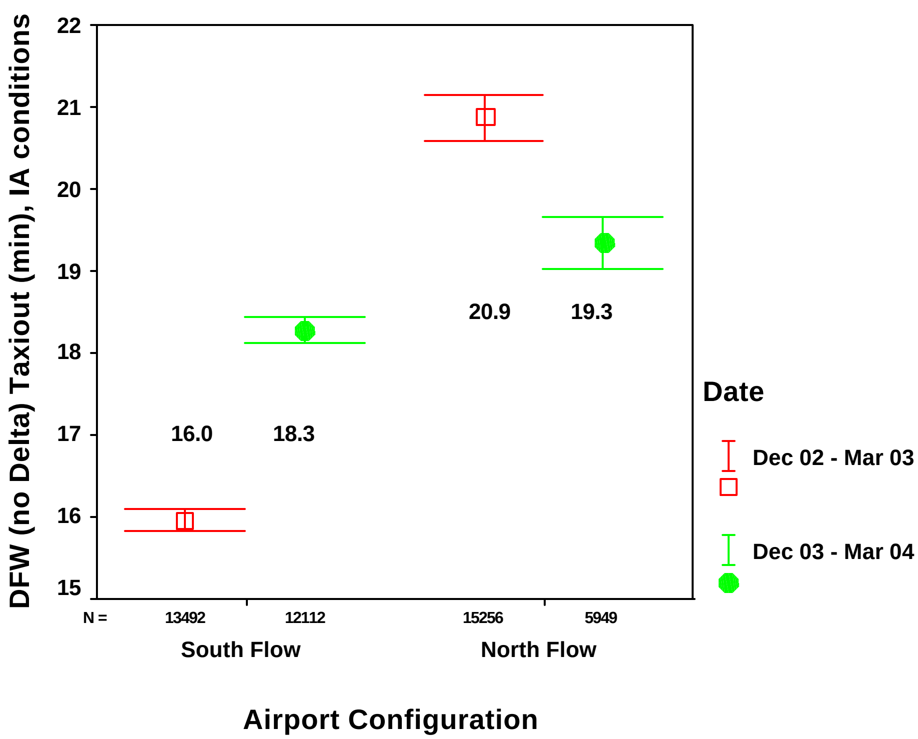

Figure 2-24. Taxi-out times at DFW before and after surveillance in IA conditions, All Other Airlines

Table 2-2. DFW Taxi-Out Time Comparison

	Taxi-out Time Change (min)			
	Visual Approaches		Instrument Approaches	
	South Flow	North Flow	South Flow	North Flow
Delta Air Lines	-0.5	-0.5	Not significant	-2.3
All Others	+1.3	+1.1	+2.3	-1.6

2.3.3 Shared Surface Surveillance Data at MEM

2.3.3.1 System Description and History

ATO Technology Development assisted Federal Express (FedEx) and Northwest Airlines (NWA) in obtaining data for surface surveillance systems for use by ramp controllers and others within these airlines to whom this information is useful. The input for this system currently comes from ASDE multilateration. Both FedEx and NWA have tested a variety of commercially available surface management tools to display and process the current data and are actively trying to determine the value of this new information. The multilateration data is also being used as the primary input for the Surface Traffic Management System (STMS). STMS is a decision support tool for the ATC tower that will use surface surveillance information to provide accurate arrival/departure demand, predicted pushback times, and runway utilization. ATO Technology Development is transferring responsibility for data sharing to the Terminal Services Division during FY2004.

2.3.3.2 Metrics Activities

FedEx has been using surface surveillance data since early 2003 to enhance surface awareness for controllers in the ramp tower and dispatchers in the systems operations center. As we began to examine benefits at MEM, an opportunity arose to perform a quick study of taxi times. FedEx lost data tags for their surface surveillance system due to a hardware conflict during the FAA installation of the Standard Terminal Automation Replacement System (STARS) on October 27, 2003. The issue was resolved and data tags reappeared on December 17, 2003.

2.3.3.3 Metrics Output

In the following analysis, we gauge the operational impact of surface surveillance by examining taxi times for FedEx aircraft at MEM before, during, and after the loss of data.

While we hope to find a change due to surface surveillance, we are certain that the taxi times are heavily influenced by demand, runway configuration, and the weather. Our first step is to isolate taxi data with like traffic, runway, and weather conditions for periods with and without surveillance. However, if we focus too tightly, we will not have enough data to come to any statistical conclusions.

We use ASQP OOOI (Out Off On In) data, runway configuration data, and weather data all recorded on the Airport System Performance Metrics (ASPM) database. Approximately 60 percent of FedEx flights record ACARS data. FedEx provided taxi times for their non-ASQP Boeing 727 fleet over the same time period. Together, this data represents over 90 percent of the fleet.

We chose to examine dates between 8 September 2003 and 11 February 2004 because we wanted to inspect seven-week periods before, during, and after the unexpected outage. Figure 2-25 displays the FedEx traffic load (all flights, not just ASQP) at MEM over the time period. During the holiday season, the daily traffic load can increase by as much as 25 percent. Because the increase in traffic affects the taxi times in a way that was difficult to model, we decided to remove data during this time.[4]

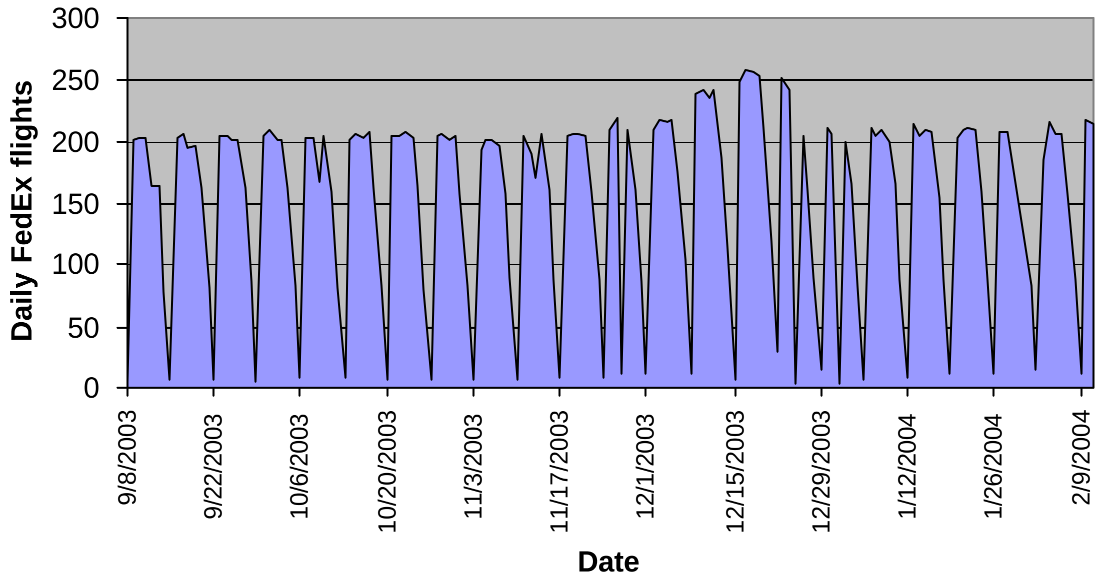

Figure 2-25. FedEx Arrivals at MEM, 9/8/2003-2/11/2004

ASPM also records runways in use for each fifteen-minute period in a day. The recorded data lists each of the open runways, but MEM primarily operates in one of two runway configuration modes: North flow and South flow. During a particular flow, most of the flights arrive and depart facing the direction of the flow. Since FedEx is located on the North side of the airport, departures during a North flow must taxi all the way to south end of the airport to takeoff. Consequently, we expect that taxi-out times during a North flow will be longer than during a South flow. For arrivals, we expect taxi-in times to be longer during a South flow than during a North flow.

From 11 February 2003 to 11 February 2004 there were approximately 54,000 FedEx flights recorded in ASPM. We were able to determine runway configuration for 91 percent of these flights (there were a few times when the runway configuration was not recorded in ASPM).During these flights, MEM operated in North flow 61 percent of the time and in a South flow 39 percent of the time.

[4] We did not include data from 24 November 2003 through 5 January 2004.

The last factor we consider is the weather. This is the most difficult variable to take into account. ASPM records airport surface visibility and ceiling. From these variables, there is an algorithm that divides the weather into Instrument Approach conditions (IA) or Visual Approach conditions (VA). To qualify for VA conditions, the visibility must be greater than five miles and the ceiling must be greater than 5,000 feet. While this is a gross simplification of weather effects, this division should help isolate periods of relatively good and bad weather. We expect that average taxi times will increase during bad weather.

As mentioned before, there were approximately 54,000 FedEx flights recorded in ASPM. Seventy-five percent of these flights operated in VA conditions, and 25 percent in IA conditions.

Our examination of impact begins with an examination of taxi-out times during North Flow operations. FedEx suggested this examination because they believe the surface surveillance information is most valuable during times of North flow.

Figure 2-26 displays the average taxi-out times for FedEx aircraft during North flow operations separated into times before, during, and after the surveillance outage. The graph shows separate measures for IA conditions and VA conditions. The annotations on the graph are the mean values. The error bars represent the confidence interval around the mean. In general, if the confidence intervals for two averages do not overlap, the difference between the two means is significant to higher than the 95 percent level. We also checked the significance of the difference in the means using an independent samples T-test.

As expected, the average taxi-out time during IA conditions is larger than during VA conditions (approximately 4-6 minutes longer). The means before and after the outage are very consistent, suggesting that they are part of the same distribution. The mean taxi-out without surveillance (during outage) was at least 1.3 minutes longer during VA conditions and 4.3 minutes longer during IA conditions. Since MEM uses a North flow 61 percent of the time, this difference represents a large yearly benefit of surface surveillance for FedEx in terms of fuel and crew costs.

Another way to gauge the impact of surface surveillance is to examine the number of flights with excessive taxi times. In this case, we define excessive as greater than 40 minutes. Not only do these flights garner higher than average fuel and crew costs, but they also have a greater chance of affecting the downstream operation.

Figure 2-27 displays the percentage of FedEx flights with taxi-out times longer than 40 minutes during North flow operations. The graph shows separate measures for IA conditions and VA conditions, and divides data into periods before, during, and after the surveillance outage.

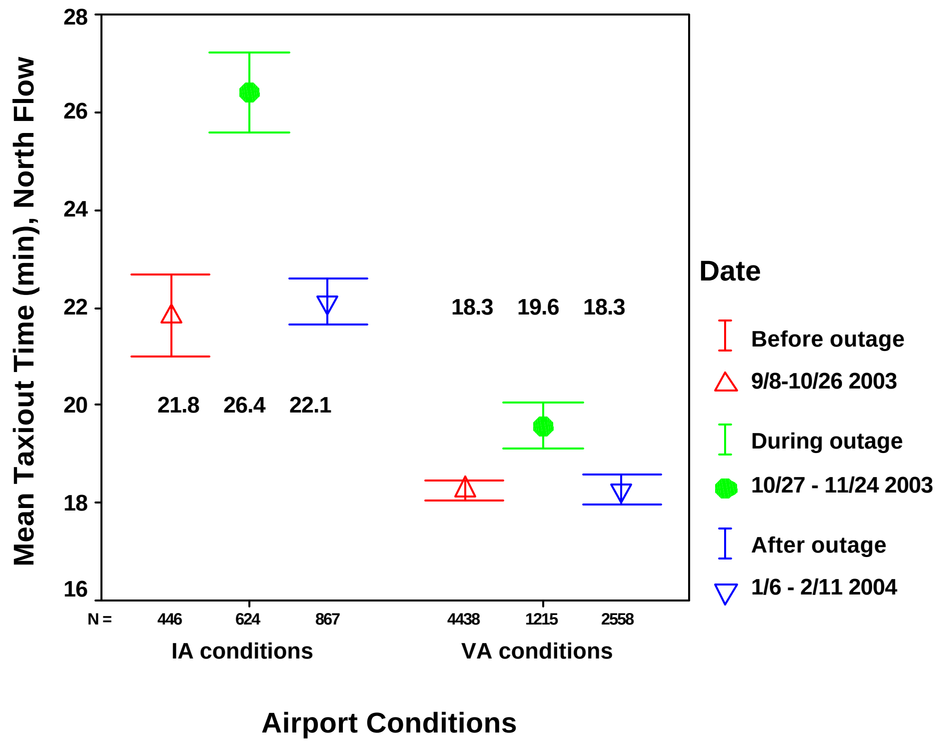

Figure 2-26. MEM Taxi-out Time Comparison, FedEx Aircraft, North Flow

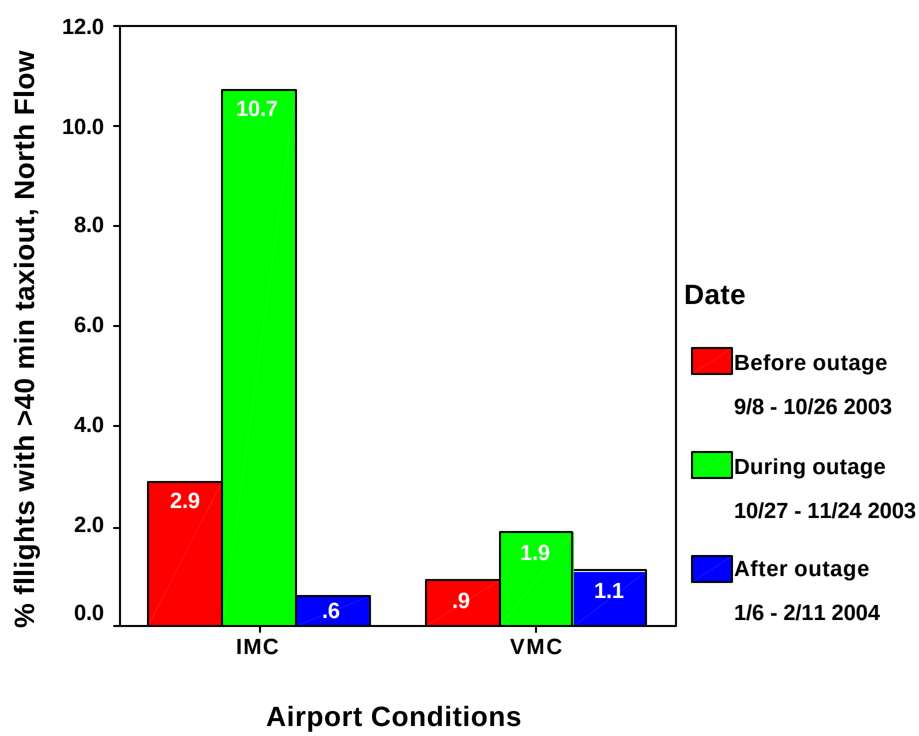

Figure 2-27. MEM Departures with >40 min. Taxi-Out, FedEx Aircraft, North Flow

In VA conditions, the percentage of flights with greater than 40 min. taxi-out times during the outage is almost double that before and after. In the IA conditions case, the difference is even greater.

Next, we examine the same taxi-out time metric for FedEx fights during South flow operations. Figure 2-28 displays the average taxi-out times for FedEx aircraft during South flow operations separated into times before, during, and after the surveillance outage.

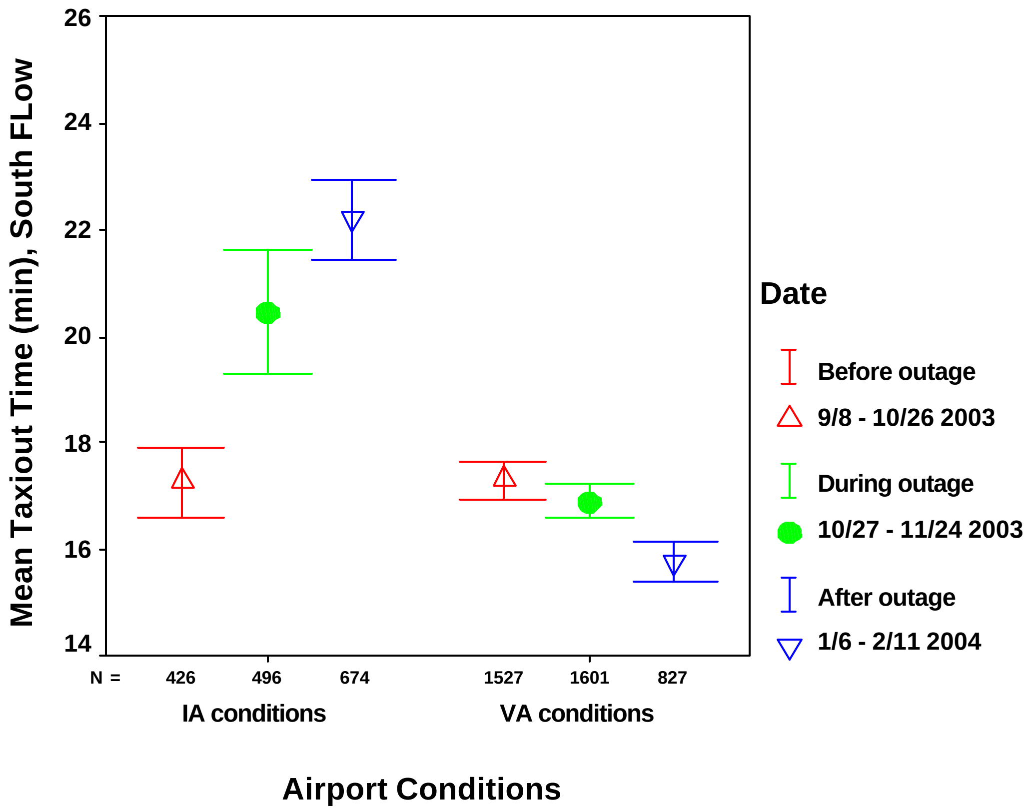

Figure 2-28. MEM Taxi-Out Time Comparison, FedEx Aircraft, South Flow

Note a few general features of Figure 2-28. The overall average taxi-out times during South flow operations are about three minutes shorter than the North flow, as expected from the position of the FedEx facilities. Also, once again the overall average taxi-out is approximately 4 to 5 minutes longer in IA than in VA conditions.

The results before, during, and after the surveillance outage for the South flow are inconclusive. In the IA conditions case, the data before the outage seems unreasonably low and the taxi-out average after the outage is greater than during the outage. In the VA conditions case, the means before and during the outage are similar, and the data after the outage is slightly lower. The variability in the data suggests that we do not have enough factors to isolate the effect of surveillance for the South flow case, or that there is little effect.

Some of the variability in the IA conditions data results from the fact that not all “bad” weather is equal. Further examination of the average ceiling during South flow finds that before the outage and during the outage the average IA condition ceiling was in the mid-3,000 ft range, while in the period after the outage the IA conditions average ceiling was 1,300 ft. This may explain the difference in taxi-out times. (For the North case, all three periods have an average IA conditions ceiling between 1500 and 2000 ft.) We could rework the analysis to focus on ceiling instead of IA/VA conditions, however the low number of observations at each ceiling value would limit the ability to make statistical conclusions.

FedEx also suggested that some of this variability comes from their changes in the sequences. Data surveillance allows them to easily change the departure order to expedite business priority flights. This can increase delay of the smaller aircraft.

In summary, when the airport is in a North flow operation (61 percent of the time), the average taxi-out time is 1.3 minutes less with surveillance during VA conditions and 4.3 minutes less with surveillance during IA conditions. For the same case, the percentage of taxi-out times that are greater than 40 minutes decreases by at least half. We also find no significant change in the taxi-out during South flow at this time.

The Air Transport Association (ATA) of America reported an average cost of $26.83 per minute for taxi-out delay in 2000. Using this estimate with the findings from the analysis, we calculate an estimated yearly benefit of $1.8 million. This estimate does not include costs from potential delays at downstream locations.

3 DECREASED EN ROUTE CONGESTION

A top level OEP goal is to reduce en-route congestion, and one OEP initiative seeks to improve en-route congestion management. Air traffic congestion can be predicted at major convergence points in the National Airspace System (NAS) based on customers' schedules and historical demand. In addition, congestion may appear at non-routine locations or at different hours based on changing wind configurations, location of hazardous weather conditions, or other dynamic shifts from the norm. Common situational awareness of a predicted congestion area shared by the customer and service provider can reveal means to collaborate on mitigation of the constraint. For example, coordination of a game plan for likely events may be done ahead of time to ensure an effective response. Results from the collaborative process used for the severe weather season of Spring/Summer 2000 were used to develop a training program, which was implemented for Spring/Summer 2001 to prepare controllers pilots, and dispatchers to manage the congestion systemically. Collaborative decision-making and information sharing will continue to be emphasized in response to en route congestion for 2004 and beyond.

Another way to reduce the impact of en-route congestion is to better accommodate user preferred routing. Today, controllers have a view of the airspace that is bounded by the sectors for which they have jurisdiction. This view limits the options available to the controller to solve problems. In addition, a fixed route structure is used to organize the airspace, providing controllers with predictable points where conflicts may arise. This fixed route structure allows controllers to maintain a three-dimensional view of the traffic situation. In some cases, however, this results in aircraft being separated from volumes of airspace rather than from other aircraft. In the current environment, flow constraints (e.g., Miles-in-Trail restrictions, ground delay programs, re-routes) are used to avoid situations where the number of aircraft being controlled by an en route sector controller is beyond the controller's ability to provide separation services. This also results in the users being constrained in their choice of flight paths.

In this report we focus on two initiatives that address these aspects of the OEP's efforts to reduce the impact of en-route congestion. First, we will examine the decision-support tools that define Flow Evaluation and Flow Constrained Areas, which help predict the effect of en-route restrictions. Second, we will discuss the User Request Evaluation Tool, a decision support tool that allows en-route controllers to trial plan user-requested flight plan changes.

3.1 Flow Evaluation and Flow Constrained Areas

Flow Evaluation Areas (FEAs) and Flow Constrained Areas (FCAs) are decision support tools that were added to the Enhanced Traffic Management System (ETMS) in the spring of 2002. An FEA is a three-dimensional volume of airspace used to identify flights subject to a potential constraint. An FCA is a similar airspace volume, but one that is placed around an actual constraint, and is accompanied by a reroute advisory. Flights predicted to pass through an FCA must take action to mitigate the effect of the constraint. FAA personnel at the Air Traffic Control System Command Center (ATCSCC), En-Route Centers (ARTCCs), and Terminal Radar Approach Control facilities (TRACONs) use FEAs and FCAs, as do customers, who gain access via the Common Constraint Situation Display (CCSD).

In the spring of 2002, functionality enabling the creation of FCAs and FEAs was added to ETMS. Initial attempts to use these tools were hampered by the lack of a clear operational concept and procedures for integrating the output of FEAs and FCAs into then-current Traffic Flow Management (TFM) processes. A working group was subsequently formed consisting of FAA personnel and system stakeholders. In June 2003 procedures for use were implemented and operational use began in earnest.

3.1.1 Description and Operational Use

A Flow Evaluation Area (FEA) is defined as a three-dimensional volume of airspace, along with flight filters and a time interval, used to identify flights subject to one or more potential constraints. System users evaluate the effect of potential constraints with FEAs, which may by public (visible to all system users), shared among several facilities, or private (for the use of a particular user or facility). Procedures govern the issuance of advisories based on the use of FEAs.

A Flow Constrained Area (FCA) is also a three-dimensional volume of airspace, along with flight filters and a time interval, used to identify flights subject to one or more constraints. Unlike an FEA, system users must take action to mitigate the effect of constraints identified by an FCA. Procedures govern the use of FCAs, which are always public, and must be accompanied by reroute advisories.

In the left panel of Figure 3-1 is illustrated a typical FEA to the northeast of Dallas/Ft. Worth International Airport (note the faint blue line). The figure shows the Traffic Situation Display (TSD), which is used by traffic managers. In the right panel of the figure is illustrated a typical FCA polygon as seen on the CCSD, along with a list of flights affected by the FCA in western Kansas.

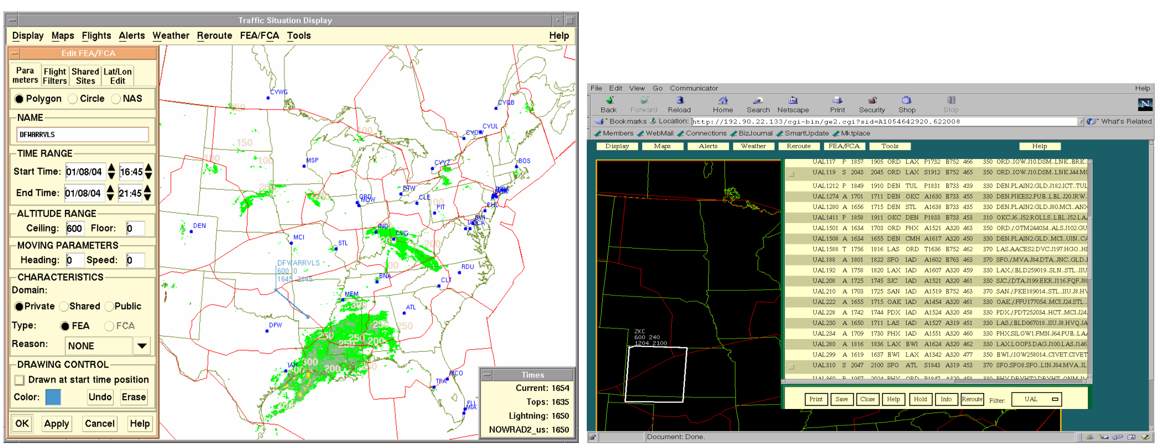

Figure 3-1. TSD FEA Display (left) and CCSD FCA Display (right)

An FEA provides users with a quick, flexible, and dynamic means by which to identify flights that will enter a defined volume of airspace, or will use specific National Airspace

System (NAS) elements such as airports, fixes, or airways. An FCA can be thought of as the point at which action must be taken to reduce the flow of traffic based upon the evaluation of a potential constraint. A constraint may be the result of a weather event, an imbalance between volume and capacity, navigational or communications equipment failures, or temporary constraints such as Special Use Areas (SUAs), Temporary Flight Restrictions (TFRs), military operations, or air shows. FEAs and FCAs have proven to be flexible and useful tools for TFM and situational awareness. As shown in Figure 3-2, FEA/FCA usage has increased steadily since tracking began in August 2003.

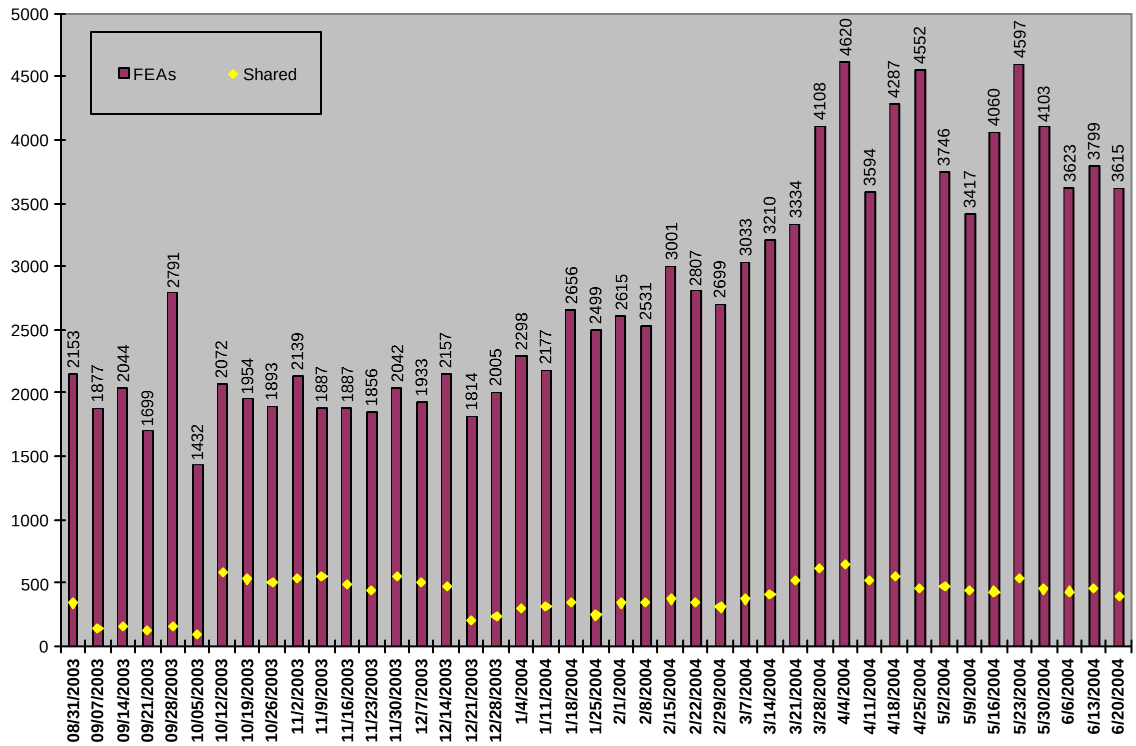

Figure 3-2. FEA/FCA – Total Created and Shared by Week since 24 August 2003

FCAs and their accompanying advisories provide system stakeholders with the ability to identify flights that must be rerouted due to some system constraint. The benefit to the FAA is the ability to quickly identify the number of flights that are subject to the constraint and to monitor this number in real time via a dynamic list. Customers also benefit from the dynamic list, saving the substantial time it can take to identify flights based on the reroute advisory criteria alone. Using the dynamic list, customers are able to select flights and apply the required reroute, updating their flight plan in compliance with the advisory.

Because it can be created privately for use at a single workstation or shared among specific facilities, the FEA has seen much broader use as an evaluation and analytic tool than the FCA. FEAs have been used as a means to justify, reduce, or eliminate the implementation of miles-in-trail (MIT) restrictions among facilities. Some ARTCCs create FEAs to monitor specific flows. For example, Cleveland Center may create an

FEA to monitor overflights bound for PHL from Chicago Center. Simultaneous FEAs can be created to monitor all the major flows through an ARTCC. The ARTCCs use the rates of aircraft crossing their boundary on these flows as a triggering mechanism to assist them in determining the need for MIT restrictions and to evaluate the duration and severity of the restriction.

Public FEAs have been used as a means by which information is shared among the community at large in order to provide enhanced situational awareness to all NAS stakeholders. The issuance of public FEA advisories has provided the FAA and flying customers with increased flexibility. Instead of a normal reroute advisory – usually a mandated reroute which essentially creates a 'no fly zone' – a public FEA provides the FAA a means by which to reduce the volume of traffic in a constrained area while at the same time providing the customers with the flexibility of choosing which aircraft to reroute. Additionally, these advisories generally allow customers to fly a User Preferred Trajectory (UPT) around the constraint, allowing them to file the most efficient flight trajectory according to their own business plan instead of an FAA mandated route.

3.1.2 User Benefits

There are several mechanisms by which users benefit from FEAs and FCAs. Public 'recommendations' generated by FEAs can reduce traffic through constrained areas to manageable levels, allowing flights to fly preferred trajectories. These trajectories often save time and distance over mandated reroutes, reducing user costs. Also, FEAs and FCAs can improve the ease, quickness, and flexibility with which FAA TFM personnel evaluate potential constraints, identify those flights affected, and share the information with other FAA facilities and customers. Customers benefit by the increased ease with which they can use the dynamic list to identify flights subject to reroutes and amend flight plans in compliance with reroute advisories.

Finally, FEAs and FCAs can reduce MIT restrictions by providing a better evaluation of restriction severity. A better definition of the duration of restrictions can lead to MIT that are shorter, and there can be fewer of them. Reduced MIT events mean fewer delays and higher efficiency.

Although data quality prevents conclusive quantification, ATCSCC log entries provide ample anecdotal evidence that FEAs are used to determine if a MIT restriction is necessary, can be reduced, or can be cancelled. Some examples of these log entries follow:

- FEA used to justify MIT restriction on ZBW entries to ZOB
  - ZOB/ZBW...20 MIT, ORD, 1400-1445, TERM VOL. 10 ACFT. *JUSTIFICATION: FEA SHOWS 10 ACFT FROM ZBW*, ZOB ADDING 8 INTERNAL DEPARTURES, BLENDING TWO STREAMS AND PROVIDING ZAU WITH 10 MIT.
- FEA Used to reduce MIT on ZBW entries to ZNY
  - CREATED AND REVIEWED CLT FEA. FEA SHOWS 6 ACFT FROM ZBW ALL OF WHICH ARE IN THE FIRST 15 MINUTES OF THE RESTRICTION. ZNY ADDING 4 INTERNAL DEPARTURES

SPREAD OVER A 45 MINUTE PERIOD. DISCUSSED FEA WITH ZNY AND THEY *<u>AGREED TO REDUCE THE ZBW MIT RESTRICTION TO ZBW</u>* .

- FEA used to cancel MIT on ZBW entries to ZNY
  - ZNY/ZOB...30 MIT, IAD, 1900-2000, TERM VOL. JUSTIFICATION: FEA SHOWS 12 ACFT FROM ZBW, 5 ACFT FROM ZOB. 13 ZNY INTERNAL DEPARTURES TO BLEND. THE LAST 30 MINUTES OF THE ZOB RESTRICTIONS SHOWS NO ACFT SCHEDULED IN THAT TIME FRAME. DISCUSSED WITH ZNY AND THEY WILL *<u>CANCEL AS SOON AS POSSIBLE</u>*.

3.2 User Request Evaluation Tool (URET)

URET is a decision support tool designed to aid ARTCC controllers in the en route environment. The primary function of URET is to alert controllers to conflicts between aircraft (up to 20 minutes in advance of the conflict) and to conflicts between aircraft and airspace (up to 40 minutes in advance). URET provides controllers with a trial planning capability to create a conflict-free amendment that can be sent directly to the Host Computer. URET also manages flight data electronically, reducing the need for paper strips. URET has been shown to increase the number of direct routings given to aircraft, reducing flight times and thereby saving fuel. Because of URET, Centers have been able to reduce the number of static altitude restrictions in place, which also saves fuel.

Prototype URET systems developed by the MITRE Center for Advanced Aviation System Development were in use at two ARTCCs, ZID and ZME, for several years before Lockheed-Martin-built production versions were deployed. The prototype variants with two-way Host communication provided capabilities comparable to those of the production systems. The first production version of URET, known as the Core Capability Limited Deployment (CCLD), was installed at six ARTCCs between December 2001 and April 2002, and included replacements for the prototype sites. The Phase 2 version of URET began to be deployed in August 2003 at ZJX, and will be rolled out to all twenty ARTCCs in the continental U.S. over the next two years. The Initial Daily Use (IDU) dates (when controllers began routinely using URET) for the prototypes, CCLD, and URET Phase 2 are shown in Table 3-1.

3.2.1 Description

The key URET capabilities include:

- Trajectory modeling
- Aircraft and airspace conflict detection
- Trial Planning to support conflict resolution of user or controller requests
- Electronic flight data management.

Table 3-1. URET Initial Daily Use (IDU) Dates

ARTCC	Two-Way Prototype	CCLD	Phase 2
ZID	June 29, 1999	January 26, 2002	January 25, 2004
ZME	June 29, 1999	January 27, 2002	February 28, 2004
ZKC		December 3, 2001	September 14, 2003
ZOB		January 28, 2002	March 20, 2004
ZAU		February 25, 2002	May 29, 2004
ZDC		April 12, 2002	April 26, 2004
ZJX			August 26, 2003
ZFW			November 14, 2003
ZMP			December 5, 2003
ZDV			February 6, 2004

URET processes real-time flight plan and track data from the Host computer system. These data are combined with local airspace definitions, aircraft performance characteristics, and winds and temperatures from the National Weather Service to build four-dimensional flight trajectories for all flights within or inbound to the facility. URET also provides a "reconformance" function that continuously adapts each trajectory to the observed position, speed, climb rate, and descent rate of the modeled flight. Neighboring URET systems can exchange flight data, position, reconformance data, and status information in order to model accurate trajectories for all flights up to 20 minutes into the future.

URET maintains "current plan" trajectories (i.e., those that represent the current set of flight plans in the system) and uses them to continuously check for aircraft and airspace conflicts. When a conflict is detected, URET determines which sector to notify and displays an alert to that sector up to 20 minutes in advance for aircraft-to-aircraft conflicts and up to 40 minutes in advance for aircraft-to-airspace conflicts. Trial planning allows a controller to check a desired flight plan amendment for potential conflicts before a clearance is issued. The controller can then send the trial plan to the Host as a flight plan amendment.

These capabilities are packaged behind a Computer Human Interface (CHI) that includes both textual and graphical information. The text-based Aircraft List helps the controller manage flight data electronically, reducing the dependence on paper flight strips. The Plans Display manages the presentation of current plans, trial plans, and conflict probe results for each sector. The Graphic Plan Display (GPD) provides a graphical capability to view aircraft routes and altitudes, predicted conflicts, and trial plan results. In addition, the point-and-click interface enables quick entry and evaluation of trial plan routes, altitudes, or speed changes, and enables the controller to send flight plan amendments to the Host. For more details about URET capabilities, benefits, and the operational concept, please see Reference 7.

3.2.2 Operational Use

The operational use of URET is gauged by measuring the number of trial plans created and the number of amendments sent to the Host through URET. Data obtained directly from the Host and URET allowed measurement of the number of direct amendments, which are those that decrease distance, measured from the point of the amendment to the destination airport.

Table 3-2 shows the yearly average number of direct amendments per day initiated by HOST and URET, the yearly average number of URET-initiated direct amendments per day, and the percentage of directs initiated by URET for June 2003 through May 2004 at all URET centers. (The Phase 2 centers - ZJX, ZFW, ZMP, and ZDV - have been open less than one year, and the results shown in Table 2 for these sites cover the period from IDU through May.) Over 15 percent of the amendments at all URET equipped centers were entered using URET, over 30 percent at six centers, and over half were generated by URET at ZDC.

Table 3-2. Yearly Average Directs per Day for Phase 1 Sites

ARTCC	Host and URET	URET Only	Percent from URET
ZID	3,615	723	20
ZME	1,768	556	31
ZKC	1,634	267	16
ZOB	2,487	406	16
ZAU	2,416	387	16
ZDC	2,357	1,457	62
ZJX	1,843	607	33
ZFW	1,522	512	34
ZMP	987	350	36
ZDV	1,409	456	32

Most centers use URET in all areas, but some do not. Due to airspace complexities, URET is not used at one area in Chicago Center (ZAU), while Minneapolis is still ramping up to full deployment. As of June 2004 Denver Center is using URET in all sectors.

Figures 3-3 through 3-6 show the number of amendments per day initiated by URET since IDU for the four newest sites, as measured by Lockheed Martin. All four sites – ZJX, ZFW, ZMP, and ZDV – opened within the past year, and the data show the rapid acceptance of URET at these facilities.

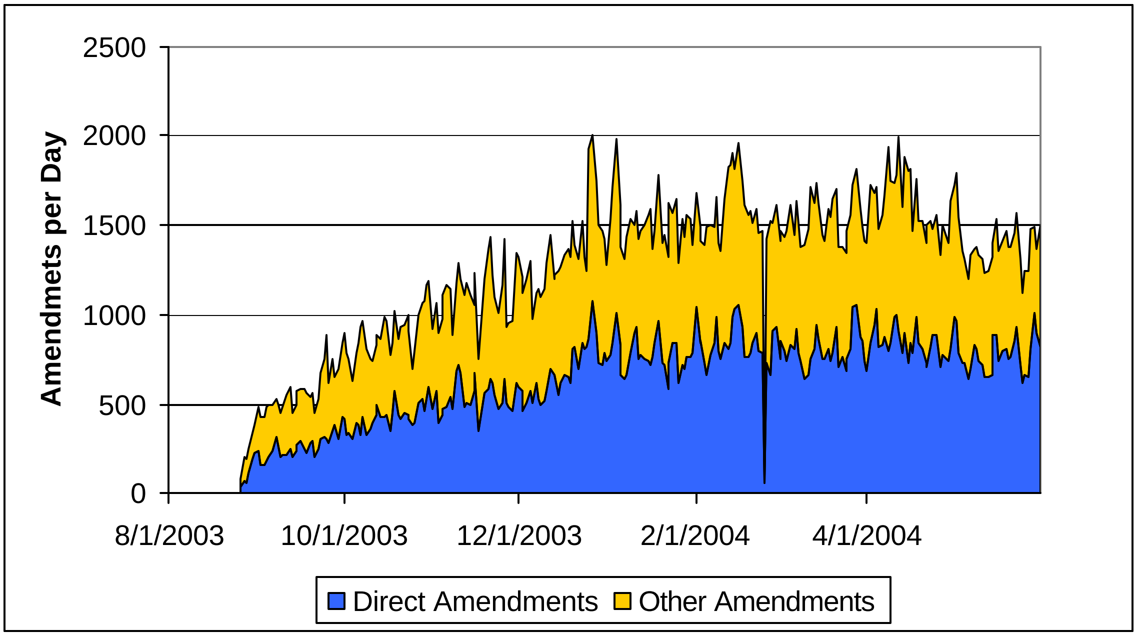

Figure 3-3. URET amendments since IDU at ZJX

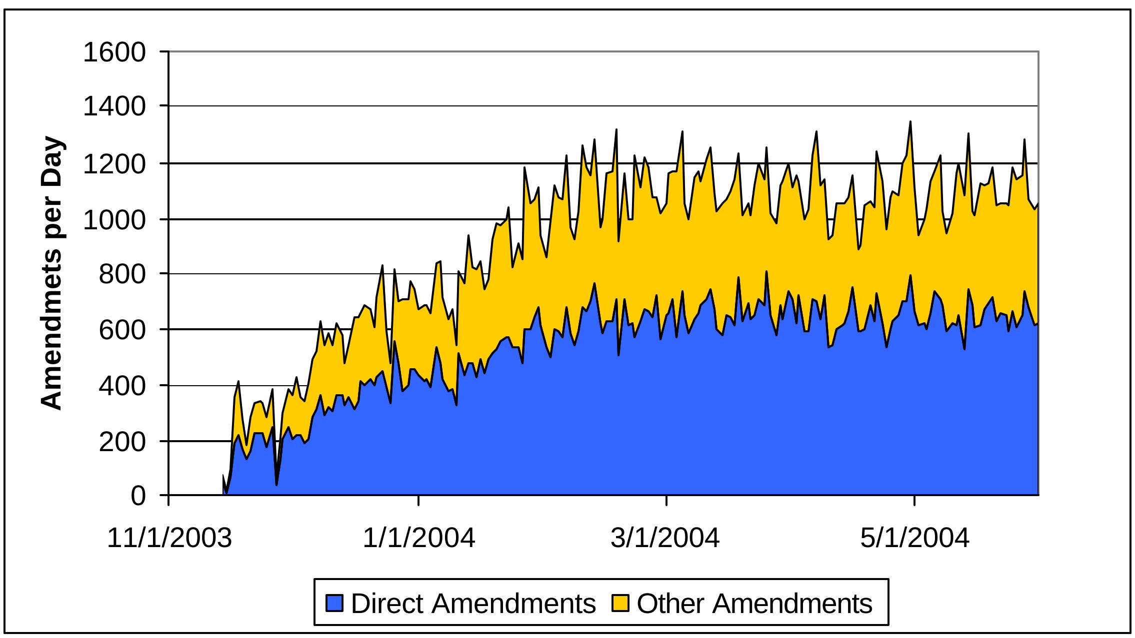

Figure 3-4. URET amendments since IDU at ZFW

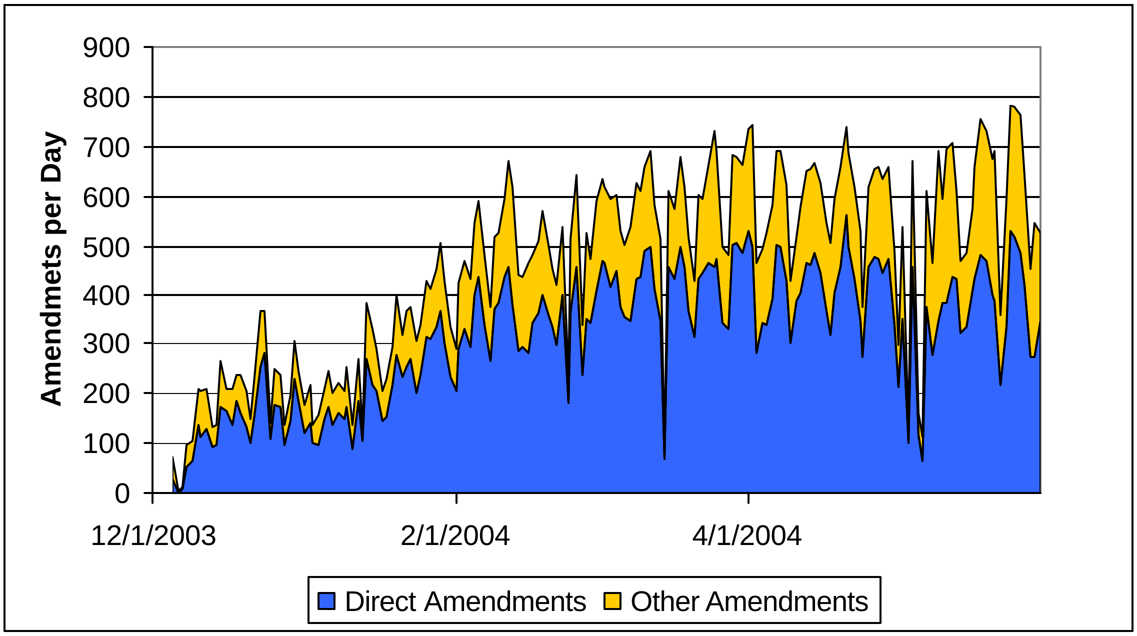

Figure 3-5. URET amendments since IDU at ZMP

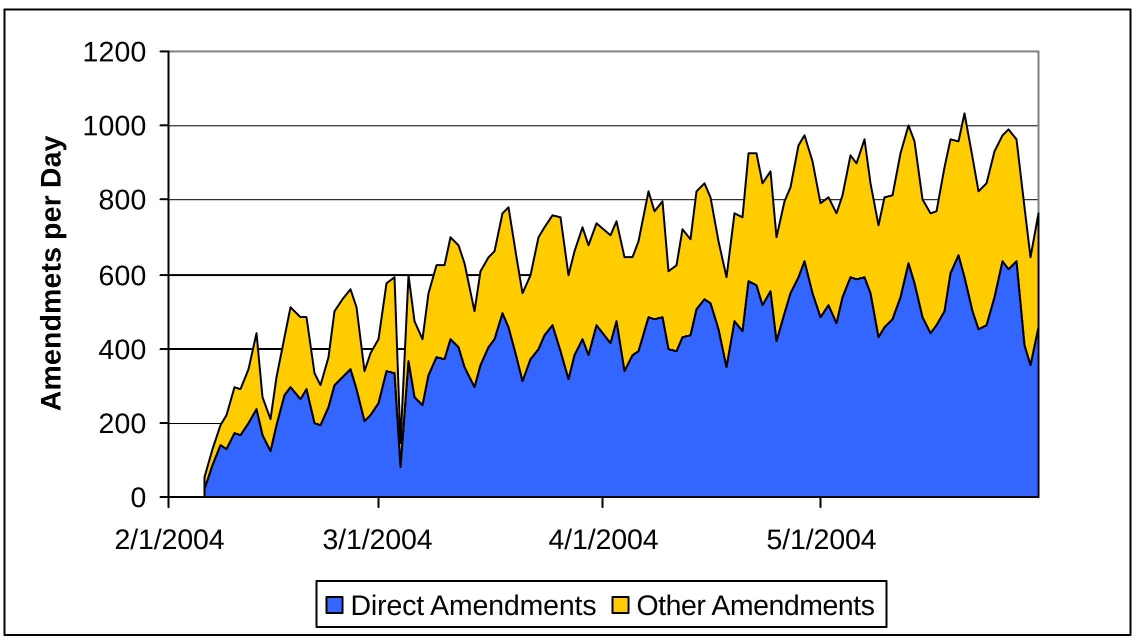

Figure 3-6. URET amendments since IDU at ZDV

3.2.3 URET User Benefits

3.2.3.1 Metrics Used

The primary metrics that address URET benefits to NAS users are distance and time saved, static altitude restrictions lifted, and increased airspace capacity. A more complete description of the distance and altitude restriction metrics may be found in the FFP1 June 2001 report (Reference [8]).

Several measures were employed to estimate the distance savings facilitated by URET. These measures include:

- Change in distance flown because of lateral amendments
- Change in average distance flown through each Center's airspace
- Change in distance flown for specific city pairs
- Change in time of flight for specific city pairs.

In addition to distance and time savings, there have been improvements in fuel efficiency resulting from the removal of altitude restrictions. The ZID and ZME Procedure and Benefits team was established to evaluate and, if appropriate, modify or remove altitude restrictions. As URET is deployed to more Centers, there is increased opportunity to eliminate inter-facility restrictions.

This report will focus on lateral amendment savings. Please refer to References 2-6 and 8-11 for information on other metrics.

3.2.3.2 Lateral Amendments

Lateral flight plan amendments are defined as those that change the direction of an aircraft but not necessarily its altitude. They can result in increases (e.g., turns to avoid congestion or heavy weather areas) or decreases in distance flown. The distance saved metric captures the average of the daily sum of distance changes resulting from lateral amendments. The data include *all* lateral amendments entered into the Host for the specified time, not just URET amendments. Figure 3-7 shows the average distance savings per day from lateral amendments at ZID, ZME, ZKC, ZOB, ZAU, ZDC, ZJX, ZFW, ZMP, and ZDV between August 2002 and May 2004 as provided by Lockheed-Martin from production versions of URET.

Note that the values for ZID are substantially higher than those for the other Centers. However, this difference is not the result of differing traffic levels, as ZAU has a comparable number of flights per day, while ZOB and ZDC have more.

The distance saved metric does not indicate the net benefit of URET to NAS users. To calculate this net URET benefit, one would need to compare the URET distance savings with the baseline case (i.e., what the distance saved would be without URET). Often the lateral savings before URET deployment is used as a proxy for this non-URET value. However, Lockheed-Martin did not begin collecting this data until August 2002, which was after IDU at the then-existing URET sites, while at ZJX, ZFW, ZMP, and ZDV data acquisition began at IDU. In the absence of a means to directly calculate the distance

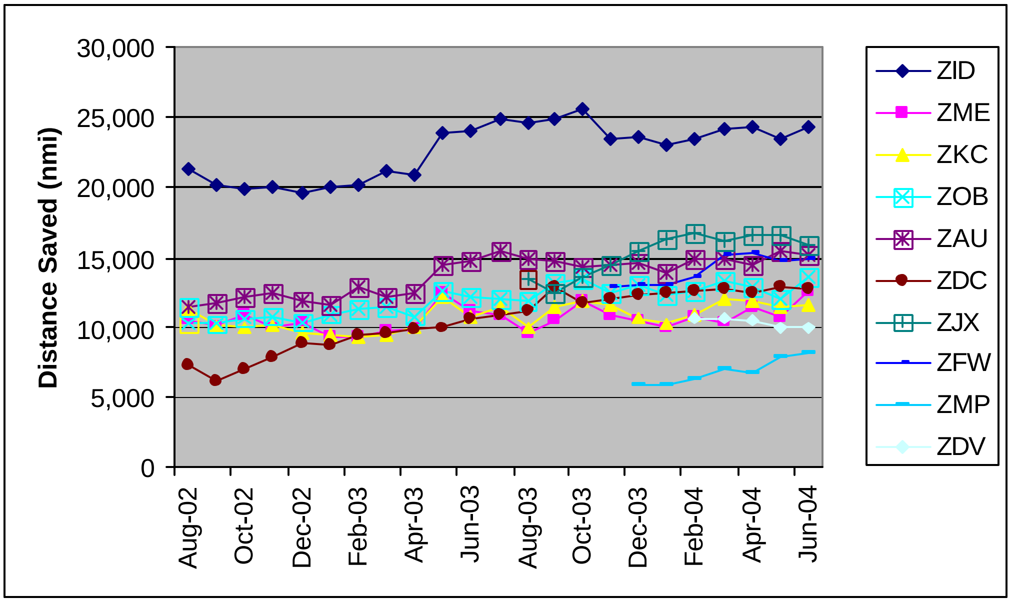

Figure 3-7. Lateral Amendment Distance Savings, Lockheed-Martin Data

saved from archived data sources, such as the Enhanced Traffic Management System (ETMS) database, one must use indirect methods to infer the savings.

One way to approach the problem is to find a measure that increases along with lateral savings. The increase in distance saved combines contributions from two possible sources: a change in the number of amendments and a change in the distance saved per amendment. In Reference 5, the number of amendments was shown to be a good proxy for the distance saved because the distance saved per amendment did not vary much with time, and was approximately the same across centers. The distance saved per amendment is plotted versus time in Figure 3-8 for all centers since August 2002 or IDU date, whichever was later. Figure 3-8 shows that the distance saved per amendment is still a constant approximately equal to 4.5 nmi/amendment.

Figure 3-9 shows the monthly average number of amendments per day at ZID for January 1998 through May 2004, where the vertical line indicates the introduction of URET. The uncorrected data is indicated by the purple line, while the blue line represents the data adjusted for seasonal effects as explained below. The number of amendments has steadily increased, but another interesting aspect of the data is that there is a pronounced period of one year. One can correct for this effect by creating a seasonality factor. (See, for example, Ref. 12). To create this factor, one calculates a rolling average of the number of amendments centered on the month to be evaluated. For example, the rolling average for July 2002 would be

$$\frac{1}{24}\cdot\left[\begin{array}{l}\sum 2\cdot\left(\text{February 2002 to December 2002 values}\right)\\ \quad +\text{January 2002 Value}+\text{January 2003 Value}\end{array}\right].$$

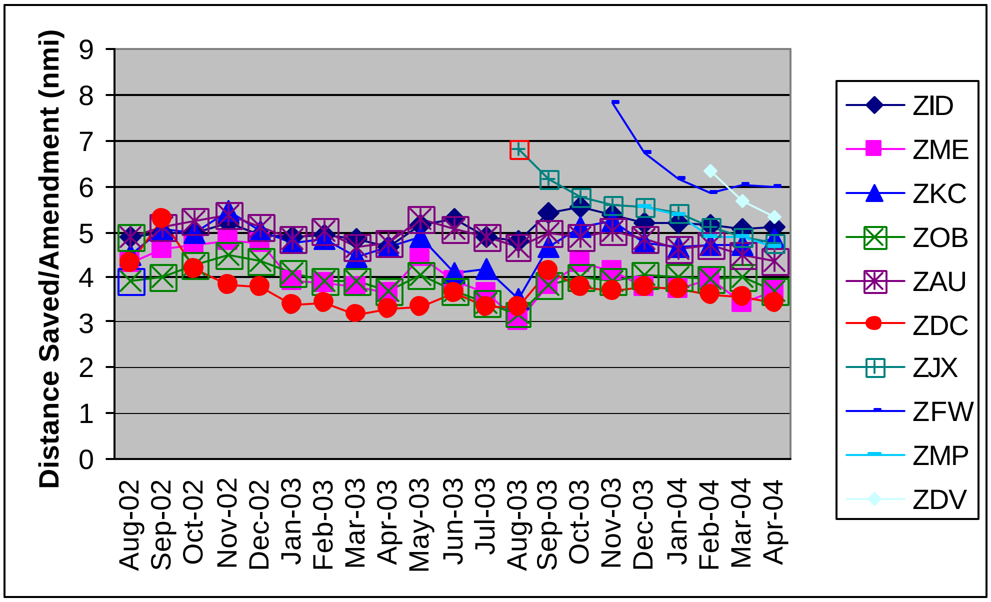

Figure 3-8. Distance Saved per Amendment

The correction factor for July 2002 would be the rolling average for that month divided by the number of amendments in July 2002. The correction factors are averaged over the years for which they are available to produce a single correction for July of every year, e.g.,

July factor = Average(July 1998 factor, July 1999 factor,…).

Finally, the correction factors are normalized so that they sum to 12. One can see that the seasonal variation apparent before the correction has been nearly eliminated by comparing the uncorrected and corrected data.

Figures 3-10 and 3-11 show the monthly average number of amendments per day for the other nine URET Centers, based on ETMS data. We can estimate the increase in the number of amendments after deployment for each Center by comparing the average of the most recent (post-URET) month to the average level for the year prior to URET deployment. The distance saved was determined from the number of amendments using a conversion factor of 4.5 nautical miles per amendment, and the results are shown in Table 3-3. The estimated distance saved for all URET Centers combined is over 60,000 nautical miles per day, or $13 million per month assuming a typical Airline Direct Operating Cost (ADOC) of $7/nmi.

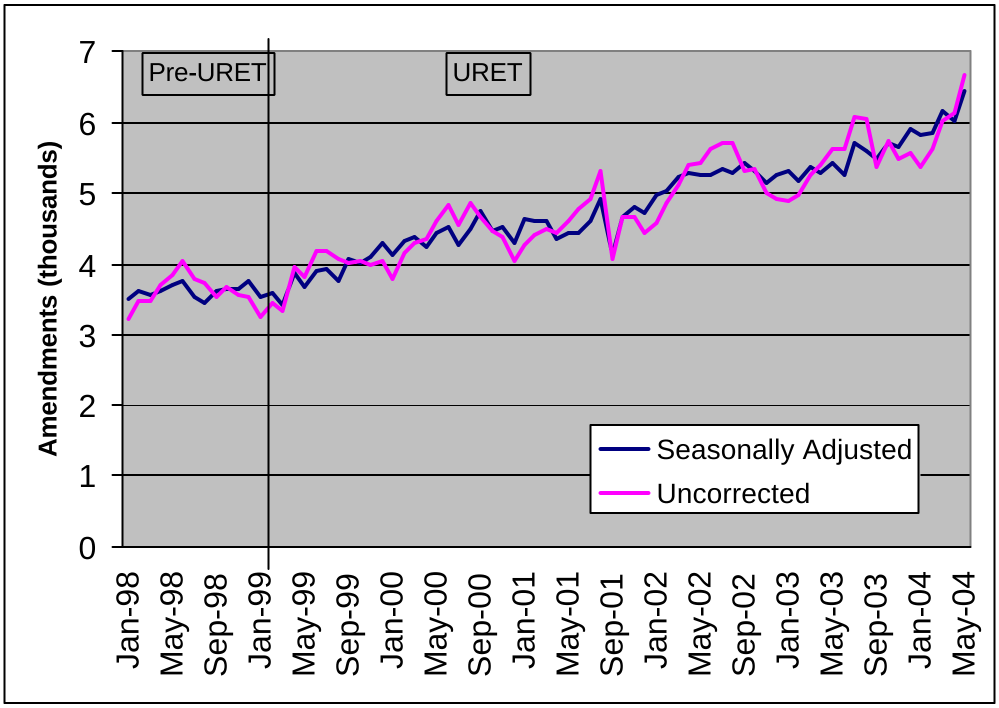

Figure 3-9. ZID Amendments

Table 3-3. ETMS Amendment Counts at URET Centers

ARTCC	Baseline (Amendments/Day)	Increase with URET (Amendment/Day)	Distance Saved (nmi/day)
ZID	3,648	2,786	12,538
ZME	2,273	1,489	6,699
ZKC	2,426	1,236	5,564
ZOB	3,886	1,007	4,533
ZAU	3,315	1,537	6,917
ZDC	2,935	2,197	9,887
ZJX	2,832	1,281	5,767
ZFW	2,227	603	2,712
ZMP	1,917	612	2,756
ZDV	2,266	607	2,732

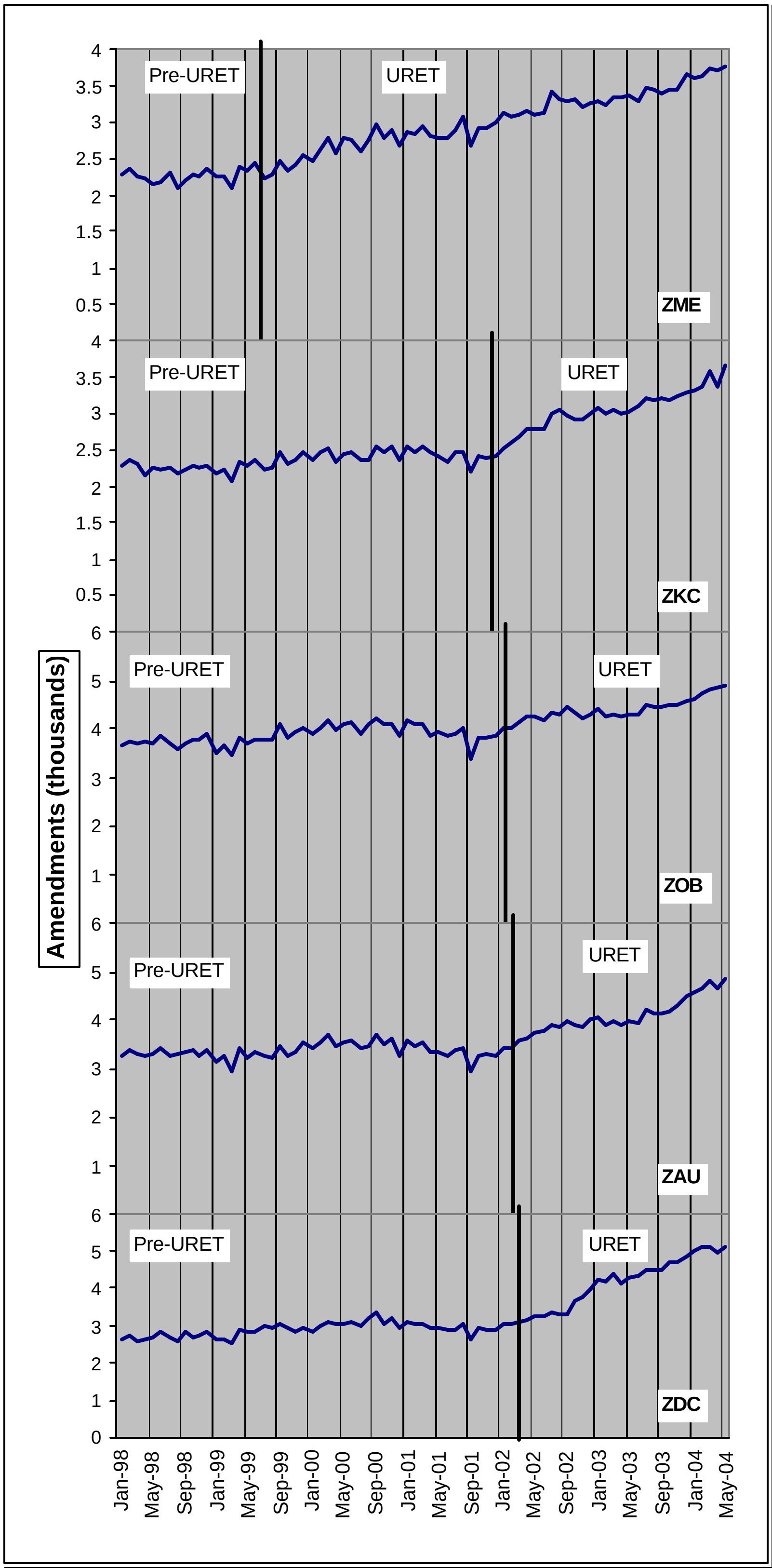

Figure 3-10. ZME, ZKC, ZOB, ZAU and ZDC Amendments, Seasonally Adjusted

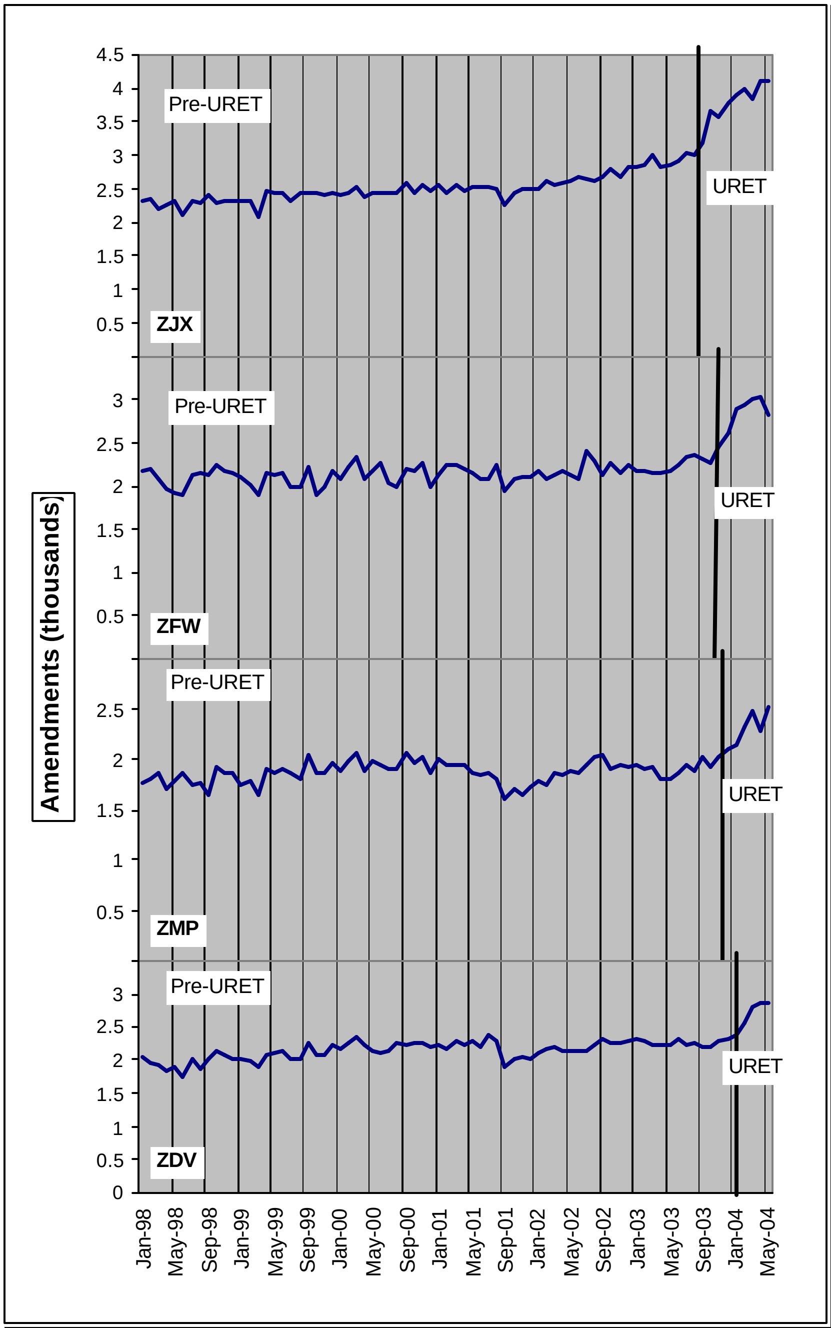

Figure 3-11. ZJX, ZFW, ZMP, and ZDV Amendments, Seasonally Adjusted

3.3 Oceanic Data Link, Advanced Technologies, and Procedures

The Advanced Technologies and Oceanic Procedures (ATOP) program, also know as Ocean21, replaces oceanic ATC systems and procedures and modernizes the Oakland (ZOA), New York (ZNY) and Anchorage (ZAN) ARTCCs. Part of oceanic modernization with Ocean21 is that it provides Controller-Pilot Data Link Communications (CPDLC) service to Future Aviation Navigation System (FANS)-1/A equipped aircraft for all three oceanic centers. FANS-1/A CPDLC is expected to provide a number of benefits to oceanic flights, including reduced communications time, which in turn leads to improved ATC services.

In June 2004, ZOA declared Initial Operational Capability (IOC) on Ocean21. ATOP IOC is scheduled for ZNY in December 2004 and in ZAN in 2005. This report will focus on the service delivery provided via the pre-existing communication system (high frequency voice radio) versus CPDLC at ZOA to verify that the benefits anticipated with full implementation of Ocean21 are achievable.

3.3.1 Description and Operational Use

Because of the line-of-sight limitations of Very High Frequency (VHF) communications, all oceanic flights have until recently used High Frequency (HF) voice radio to communicate with ground air traffic control. The pilot contacts a Radio Operator (RO) via HF with a request. The RO then communicates with the controller by manually transcribing the pilot's request into a data message and sending the message to the controller via automation. Upon reviewing the message, the controller conducts a manual traffic search of the traffic situation - a time intensive process - and coordinates as necessary with the downstream controller. The controller sends a response as a data message back to the RO, who then contacts the pilot by voice via HF radio. After receiving a clearance, the pilot first repeats the clearance message back to the RO (the "readback") and then provides his voice response to the RO. The RO transcribes the pilot's readback into a data message and reads it back to the pilot to ensure correctness. The RO then sends the message to the controller. The controller then must verify that what he issued was read back by the pilot.

For FANS-1/A flights, the pilot sends his request via satellite data link directly to the controller, with no third-party human intervention. Generally, the altitude request is automatically probed for conflicts. After reviewing the request and conflict probe results, the controller performs the same coordination as he did for an HF flight. The controller's response is sent directly to the pilot via data link by the automation and the pilot responds with a WILCO to close the communication.

ZOA has been providing CPDLC service to FANS-1/A aircraft since 1999 when Multi-sector Oceanic Data Link (MSODL) was introduced. Currently, about 28 percent of the Oakland oceanic flights are FANS-1/A capable and 98 percent of these flights use CPDLC to communicate with controllers. In preparation for the ATOP implementation, ZNY started operating with the full CPDLC message set to communicate with FANS-1/A equipped aircraft in the New York Oceanic Data Link Service Area, a subset of ZNY oceanic airspace, in March 2003. The rest of the oceanic flights in ZOA, ZNY and ZAN continue to communicate with controllers via a third-party radio operator using HF voice.

Environmental metrics provide information on flight counts, aircraft characteristics, and types of airspace users (e.g., air carrier, military). Figure 3-12 shows the number of flights per day and data link usage for Oakland airspace. Both the number of flights per day and data link usage continue to rise. As traffic levels continue to rise, a reduction in separation standards is planned (e.g., 30/30 lat/long separation) to handle increased traffic volume and to increase the user's ability to get preferred flight profiles and routings. To accommodate the reduced separation standards, efficiencies in air/ground communication for issuing clearances and for position reporting is required, thus a dependency on

CPDLC. Additionally, efficiencies in controller productivity are required to ensure controller workload remains at acceptable levels as traffic volumes increase. Ocean21, with its elimination of manual bookkeeping, automated coordination, improved situational awareness, conflict probe, and CPDLC, provides those efficiencies so controllers can focus on service delivery.

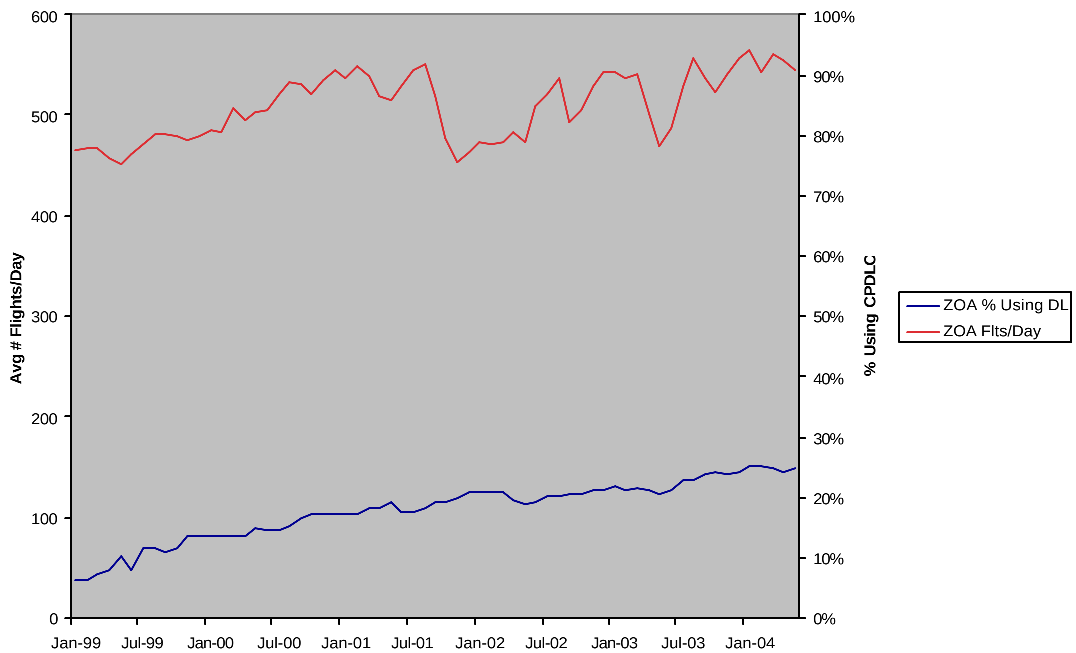

Figure 3-12. ZOA Flight Count and Data Link Usage

3.3.2 Benefits

In 1999, the Oceanic and Offshore Service Unit began establishing an operational baseline for future comparison after the ATOP system was implemented. This on-going metrics analysis was initiated to:

- Measure quality of service provided by Oceanic air traffic control
- Monitor trends and outliers
- Track performance against projected benefits
- Provide a basis for common comparison
- Assess the impact of one metric (e.g., entry altitude predictability) on another metric (e.g., flight plan change requests granted).

FANS-1/A CPDLC is expected to provide a number of benefits to oceanic flights, including reduced communications time, which in turn leads to improved ATC services. The fixed format CPDLC messages allow the ground ATC decision support tools to evaluate most flight plan change requests for conflicts automatically, and it was anticipated that this would enable controllers to respond to flight plan change requests more quickly. Only a snapshot of ZNY CPDLC data exists for May 2004 so it is not included in this paper.

Air carriers and pilots want the flexibility to change their route and altitude to minimize fuel burn and flight time, and maintain passenger comfort. As the flight progresses and fuel is burned, pilots would like to step climb to higher, more fuel efficient altitudes. The ability to avoid convective weather is a very important safety concern, thus faster handling of weather deviation and altitude change requests is important. When fuel load or traffic patterns change, or National Weather Service or Bracknell release new weather forecasts, it is beneficial for flights to be able to change their altitude or route in real time.

One important metric being monitored is response time for altitude requests as a means of tracking system flexibility in allowing users to adapt their operation to changing weather, traffic, and other conditions, and to increase user access to airspace. Figure 3-13 shows the difference in response time for altitude requests within ZOA airspace. The figure breaks out response times for altitude requests and weather related requests (i.e., altitude changes due to weather, and weather deviations). Response times include times for requests granted, modified, and denied. This figure shows that response time with CPDLC is significantly lower than HF RO, as would be expected. It also shows that introduction of data link not only allows FANS-1/A flights to communicate with ATC faster, but also reduces congestion on the channel allowing HF flights to get faster service, as can be seen starting in 1999, when MSODL was introduced at ZOA. Oceanic Data Link enhances controller productivity for all flights, not just FANS-1/A flights. As the number of FANS-1/A aircraft continues to slowly rise, the response time for altitude requests continues to slowly drop. Traffic volume at the time of the request factors into the response time. The response time for HF weather requests is less than for HF altitude requests, likewise, response time for FANS 1/A weather requests is less than FANS 1/A altitude requests, because weather deviations and altitude changes due to weather are considered safety critical clearances.

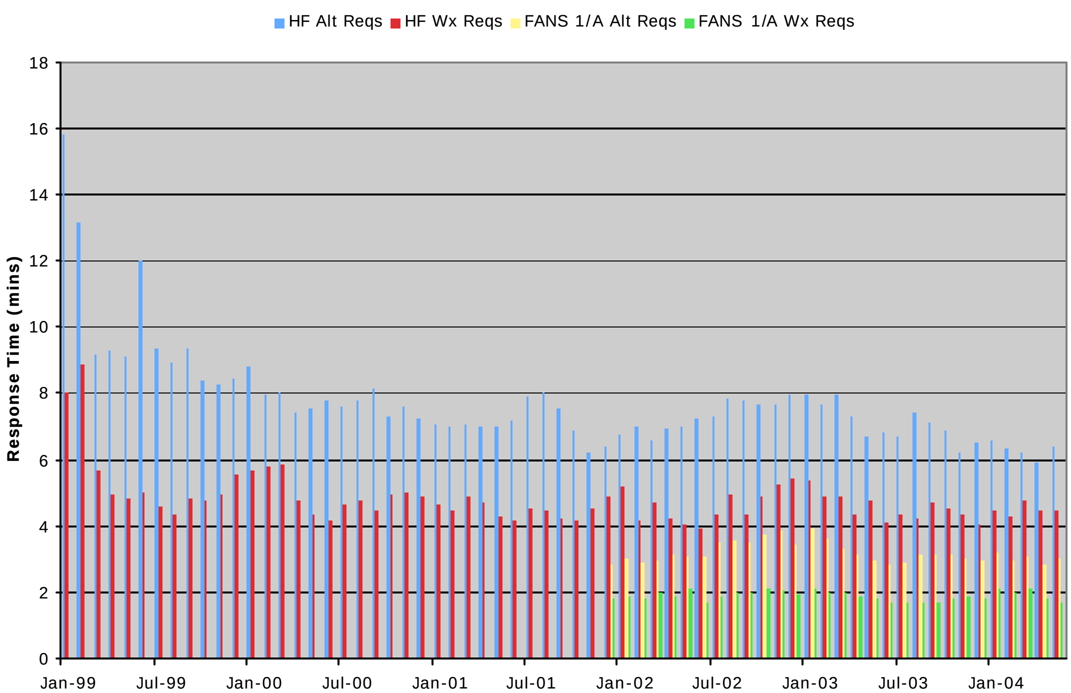

Figure 3-13. ZOA Oceanic Response Times

Figure 3-14 shows that at ZOA the total number of altitude change requests continues to rise yearly, yet the percentage of requests granted remains fairly constant. This holds true for requests communicated both over HF and CPDLC. Moreover, the percentage of requests granted is the same, regardless of communication capability, indicating that service delivery is dependent on the traffic situation, not the communications means. As separation standards in oceanic airspace decrease following ATOP implementation the potential to get preferred flight profiles increases.

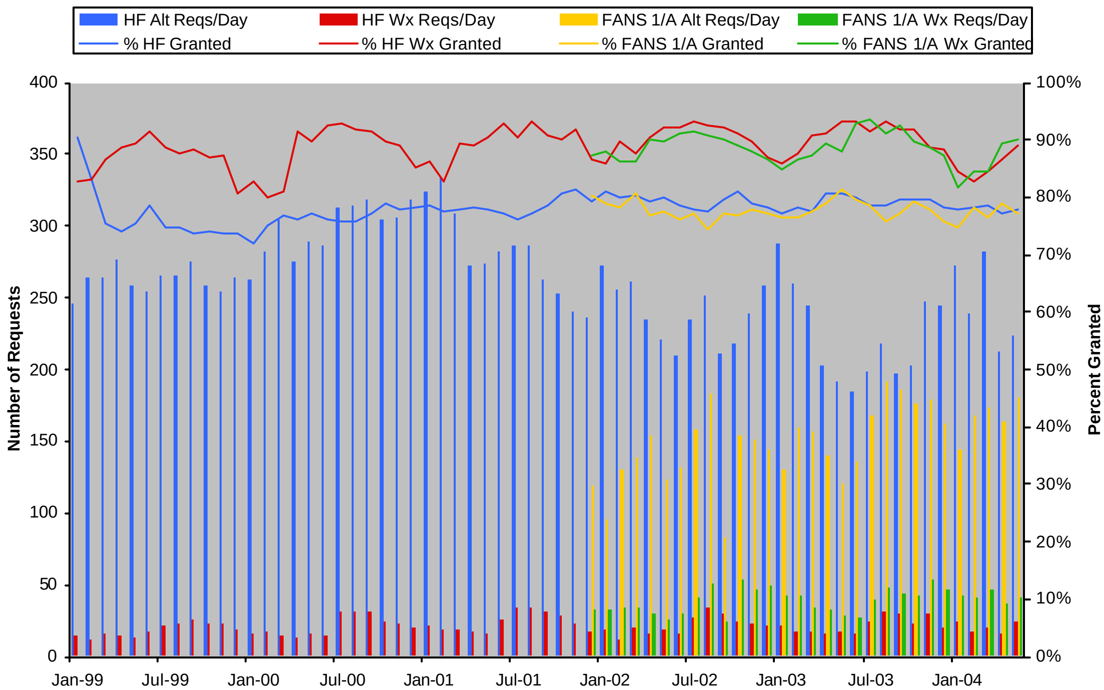

Figure 3-14. ZOA Oceanic Altitude and Weather Related Requests

3.3.3 Summary

The trends at ZOA clearly indicate that as more aircraft become equipped with FANS-1/A CPDLC, response times for altitude change requests and weather deviation requests decrease, while the percentage of change requests granted remains steady. With the implementation of Ocean21 providing CPDLC at ZOA, ZNY and ZAN, and supporting reduced separation standards, oceanic service delivery is on target for providing increased safety with reduced response times to weather related change requests, and increased flexibility for users with more altitude change requests granted.

4 IMPROVED FLIGHT DURING UNFAVORABLE AIRPORT WEATHER CONDITIONS

For the benchmark airports, inclement weather operations lower arrival and departure rates an average 18 percent. As weather or visibility degrades, runway use may become limited and spacing between aircraft is increased. To make airport operations less sensitive to weather, more options for runway configurations and more consistent spacing of operations are necessary, both of which require new technologies. Improved forecast data will also help. With RNP and improved navigation means, precision approaches become available at more airports. A variety of procedures, including wake-mitigation and flight monitoring, allow operations to increase on closely-spaced parallel runways as bad weather arrives. Cockpit Display of Traffic Information (CDTI) may enable visual approaches to continue into marginal visual flight rules conditions. A moving map display will also help with improved surface situational awareness.

Procedures for visual approaches require that the pilot visually acquire nearby aircraft and/or the runway. In marginal visibility conditions, pilots may have difficulty visually acquiring the runway or nearby aircraft, reducing arrival rates. Cockpit tools and displays can help to achieve higher throughput by enabling more rapid identification of aircraft, reducing the need for additional communications between the pilot and controller to advise on traffic. The cockpit display indicates target aircraft and trajectory information that the pilot can correlate to what is visible, providing faster target identification and helping the pilot maintain visual separation. The OEP outlines two efforts. The first is an in-service evaluation of the Enhanced See and Avoid application currently approved for use by UPS aircraft equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) operating at Louisville Standiford Airport (SDF). The second effort builds on this work by expanding the application to continue “visual” approaches to lower weather conditions. In this section we present analyses of the initial effort performed by the Safe Flight 21 (SF-21) team of ATO Technology Development.

4.1 ADS-B at Louisville Standiford Airport

4.1.1 CDTI Equipage

Our focus is measuring the impact of ADS-B/CDTI in the terminal area. UPS began equipping aircraft with CDTI systems in April of 2003. They have concentrated on B-757s and B-767s because these represent the majority of the fleet (65 percent). The UPS domestic fleet consists of 75 B-757s and 32 B-767s.

Figure 4-1 shows the number of operating CDTI-equipped aircraft from March 2003 through February 2004. The top line is the total number of aircraft and the lower two are the separate counts of B-757s and B-767s from UPS. The dotted line that starts in June 2003 is the number of ADS-B aircraft recognized by the Comprehensive Real-time Analysis of Broadcast Systems (CRABS) tool. Johns Hopkins Applied Physics Laboratory (JHUAPL) developed the CRABS tool to record and display track information from ADS-B sensors. UPS Airbus aircraft or other non-UPS ADS-B aircraft may account for the difference between the total and observed lines in Figure 4-1. The lines dip in November because the B-767s had to undergo a system modification at that time.

4.1.2 Benefits

4.1.2.1 Decreased communication time between pilots and ATC

Problem: Due to the lack of identification, speed, and heading information on current traffic displays (e.g., TCAS), pilots may require additional information when trying to acquire or identify aircraft and when they do not understand the traffic flow. This lack of information can lead to more calls or longer calls between the pilot and ATC requiring confirmation of approach type, location of lead aircraft, and other ATC directions.

Capability/Direct Impact: The CDTI aids the pilot in identifying, visually acquiring, and maintaining sight of equipped aircraft, and may provide the pilot insight into the overall traffic flows. The addition of a call-sign procedure may aid the pilot in the positive identification process.

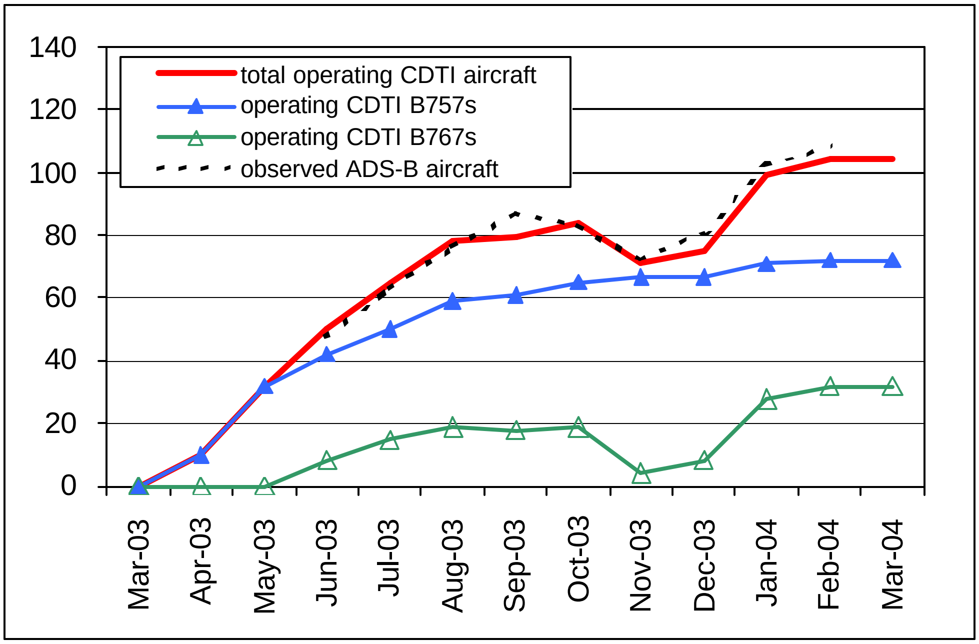

Figure 4-1. Operating CDTI Units, March 2003 – March 2004

Outcome/Benefit: Increased pilot ability to acquire, identify, and maintain sight of lead aircraft and monitor the overall traffic flows should lead to fewer or shorter calls between pilots and ATC. Reduction in communication time allows more time to focus on other ATC and flight deck activities. The reduction should also allow for increased access to the frequency.

Evidence: We use audio loading to examine this impact. CRABS records communication time intervals from radio frequencies at SDF.

This analysis compares audio loading curves from an ATC Terminal frequency. Figure 4-2 shows the average audio loading for the ATC Terminal frequency as an example. The figure shows the three main busy intervals experienced at SDF as the result of UPS operations between 0300 and 1130 GMT. Referring to Figure 4-2, interval 1 is associated with the UPS aircraft arriving from the Midwest and east coast locations. Interval 2 is associated with aircraft arriving from west coast locations. Interval 3 is associated with all of the UPS aircraft departing the airport. A baseline was collected between September and December of 2003. Figure 4-3 shows the loading for January and February 2004 compared to the baseline.

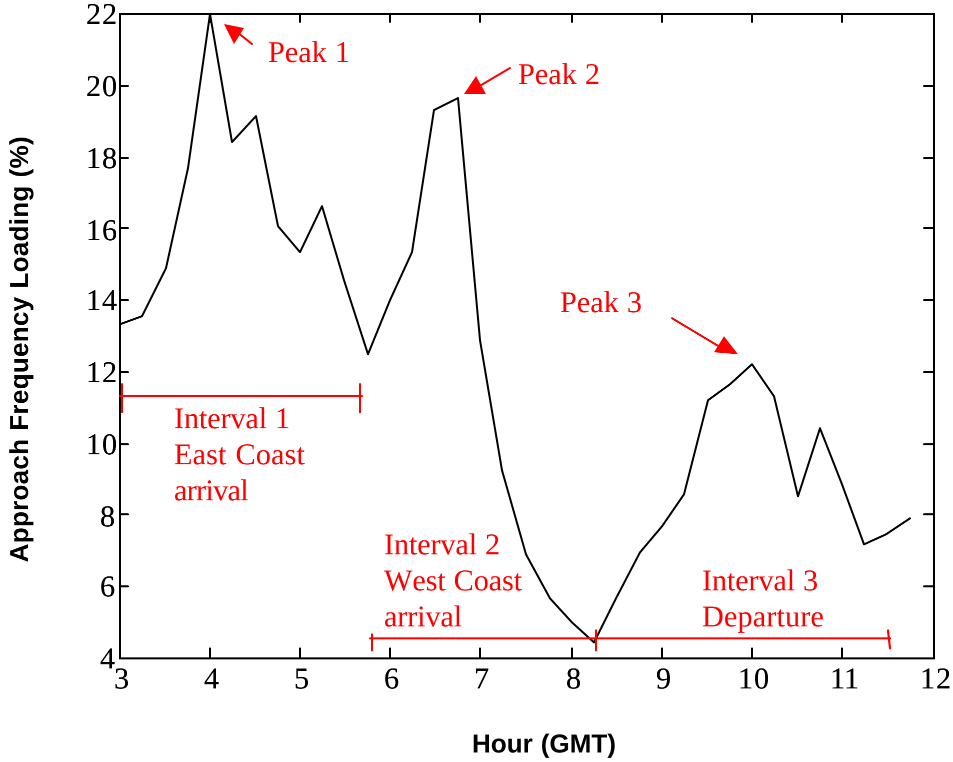

Figure 4-2. Definition of the audio loading statistics

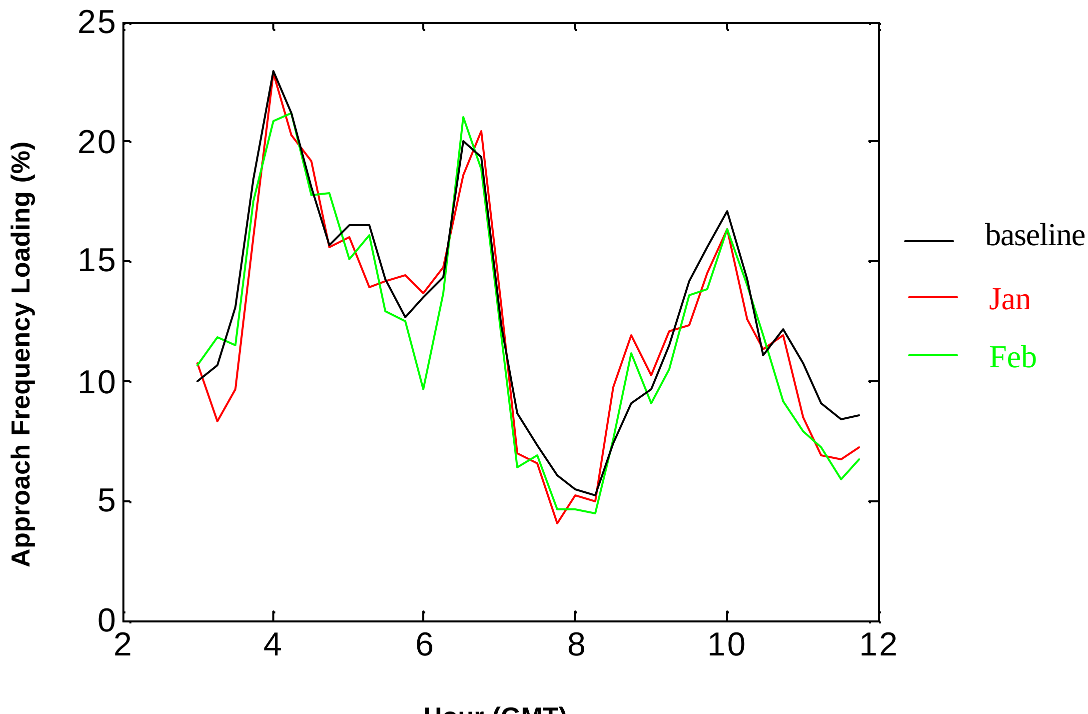

Figure 4-3. Terminal Frequency Loading Comparison

The audio loading statistics attempt to characterize the entire audio loading response with a few simple numbers. The statistics measure the ratio of the peak loading during the interval to the average loading during the interval. As the system becomes more efficient, the ratio should decrease towards a uniform audio loading. A second statistic is the total integrated area under the audio loading curve for all three intervals. This is a measure of the total operator workload on the audio system. This total audio workload should decrease as the system becomes more efficient. Table 4-1 shows the computed statistics for the months January and February minus the baseline period. A negative value demonstrates a reduction from the baseline. There was approximately a 5 percent reduction in total integrated audio loading for the ATC terminal frequency during the Jan/Feb period. All other statistics showed no significant difference between the audio loading in the Jan/Feb 2004 period when compared to the baseline.

Table 4-1. Terminal Frequency Loading Statistics Relative to Baseline Period

Month	Total Integrated Loading (min)	Interval 1			Interval 2			Interval 3		
		Peak (%)	Avg (%)	Peak /Avg (%)	Peak (%)	Avg (%)	Peak /Avg (%)	Peak (%)	Avg (%)	Peak /Avg (%)
January	-2.9	-0.1	-0.7	0.06	0.4	-0.1	0.07	-0.7	-0.4	-0.01
February	-4.2	-1.7	-0.3	-0.08	1.0	-0.7	0.25	-0.6	-0.9	0.07

4.1.2.2 Greater arrival/departure capacity and more efficient terminal operations

Problem: Pilots have limited ability to maintain efficient spacing during visual approaches, because of the lack of identification, speed, and heading information on current traffic displays. Lack of insight into the overall traffic flows can also lead to delayed pilot reactions to ATC directions and poorer traffic awareness, which may also lower efficiency. Also, at night and in some marginal visual conditions pilots may not accept a visual approach because it is difficult to keep the lead aircraft in sight. Visual approaches increase the capacity of the airport, thereby increasing terminal efficiency.

Capability/Direct Impact: CDTI aids the pilot in maintaining sight of lead equipped aircraft, maintaining efficient spacing from equipped aircraft during approaches, and monitoring the overall traffic flows.

Outcome/Benefit: Increased pilot ability to maintain sight of lead aircraft, maintain efficient spacing from lead aircraft, and monitor overall traffic flows should increase the efficiency of terminal operations and consequently increase airport capacity. Increases in terminal operation efficiency lead to increases in arrival/departure rates and decreases in flight times in the terminal area.

Evidence: Our first examination of terminal efficiency considers flight time and distance of UPS arrivals into SDF. We can directly relate flight time measurements to fuel burn, but the average flight time from day-to-day varies dramatically because of the wind. Flight distance measurements are less affected by the wind; however, they lack any speed change information.

Figure 4-4 displays one night of arrival flight tracks. The arrows point out rings at 40 nmi and 100 nmi from the airport center. We use these rings in the analysis to separate the flights into regions during approach. We also examined flight distances as far as 300 nmi from SDF, but found no measurable effect beyond 100 nmi.

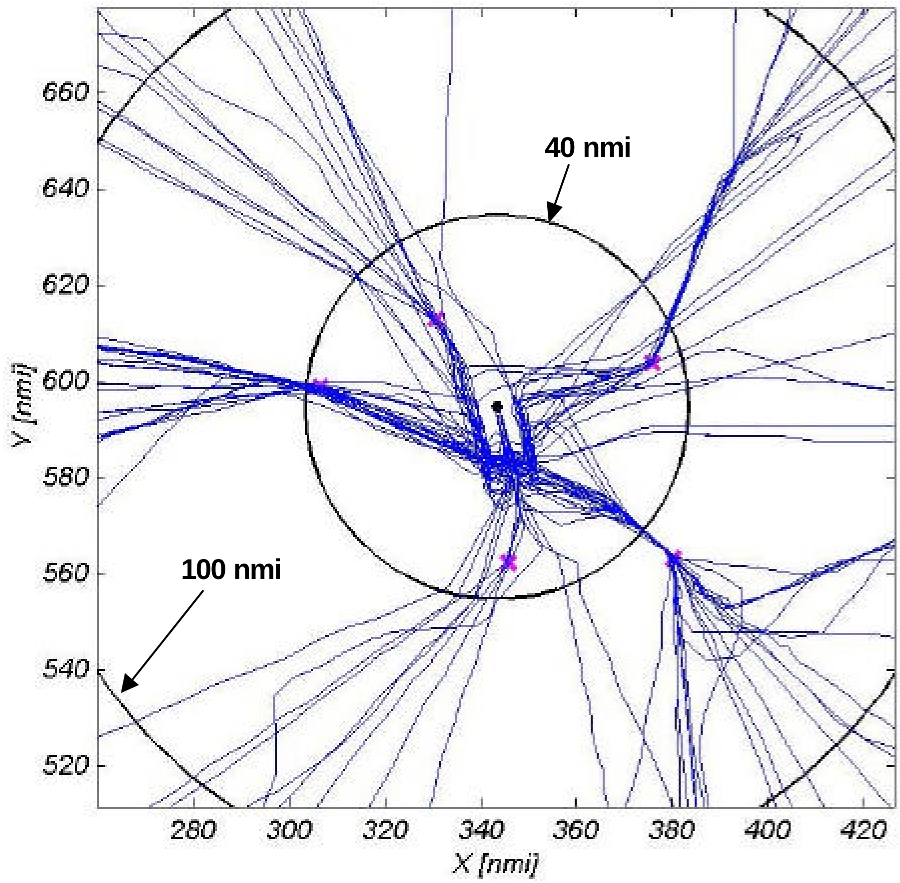

Figure 4-4. Typical SDF Arrival Flight Tracks During North Flow Operations

The flight track calculations use three data sets. Flight tracks beyond 40 nmi use Enhanced Traffic Management System (ETMS) one-minute position data. This data is fairly accurate outside of the immediate terminal area (40 nmi), but suffers some signal loss inside of SDF TRACON airspace. Also, the many changes in speed and direction necessary for an approach may not be sufficiently captured by the one-minute tracks.

Flight tracks within 40 nmi employ two different ARTS archives. Before August 2003 we use compressed ARTS III-A data archived at the FAA Command Center. This data source became inactive after SDF installed ARTS III-E. After October 2003, we use data from the UPS ARTS feed archived by JHUAPL on a monthly basis. To determine if these two archives give similar results, we compared the mean flight time and distance distributions for a day of overlap in May 2003.[5] The results of the comparison showed

[5] We received a few days in May and June from the new data source before we were able to archive continuously.

little statistical difference (well below the 95 percent level) in the flight time and distance means.

By Jan 2004, over 90 percent of the B-757/B-767 domestic fleet included operating CDTI displays (See Figure 4-1). The B-757/B-767 fleet comprises 65 percent of the total UPS fleet. The metrics group decided that January 2004 would be a good starting point to observe the impacts of CDTI/Enhanced Visual Approach. In the following analysis, we use data from January 1, 2004 through March 12, 2004 for the post-implementation data set. We chose baseline dates (January 1, 2003 through March 12, 2003) to include similar types of weather and demand. The analysis is data set contains all UPS arrivals. In the post-implementation period, this includes both ADS-B equipped and non-equipped aircraft. The expected benefit to equipped aircraft should also be evident in the overall flow efficiency. The majority of UPS flights (76 percent) arrive during the night between 2200 and 0300 local time. At these times, UPS dominates operations at SDF.

To take airport configuration into account, we bin the data by runway configuration. SDF primarily operates in one of two runway configuration modes: North flow and South flow. During a particular flow, most of the flights arrive and depart facing the direction of the flow. SDF determines airport flow based on winds, runway conditions, and noise abatement procedures. For our data set, SDF operated in North Flow approximately 70 percent of the time and South Flow 30 percent of the time.

We separate weather data into instrument (IA) and visual (VA) approach conditions based on the time of arrival compared with weather reports from the ASPM database. Since we do not have access to actual approach records, we cannot be sure that visual or instrument approaches were being implemented at a specific time. However, we assume that a majority of the flights use instrument approaches during the defined IA conditions, and visual during the defined VA conditions. ASPM defines the conditions, based on SDF facility input, to be IA when the ceiling is less than 3,000 ft or the visibility is less than 3 nmi. For our data set, VA conditions occurred 70 percent of the time and IA conditions occurred 30 percent of the time. Since most of the approved applications of CDTI relate to VA, we expect to see more impact during VA conditions than in IA conditions.

Figure 4-5 compares the actual flight distances from 40 nmi to the runway in VA conditions for both runway configurations. The error bars represent 95 percent confidence intervals around the mean values. We also check for significant differences in the means using an independent samples T-test. All results below are significant to at least the 95 percent level unless otherwise noted. Figure 4-6 displays similar data for 100 nmi to 40 nmi. The results for both cases show a decrease in flight distances in VA conditions after implementation of ADS-B. The difference is not particularly dramatic from 100 nmi to 40 nmi, but it is encouraging that the trend is the same.

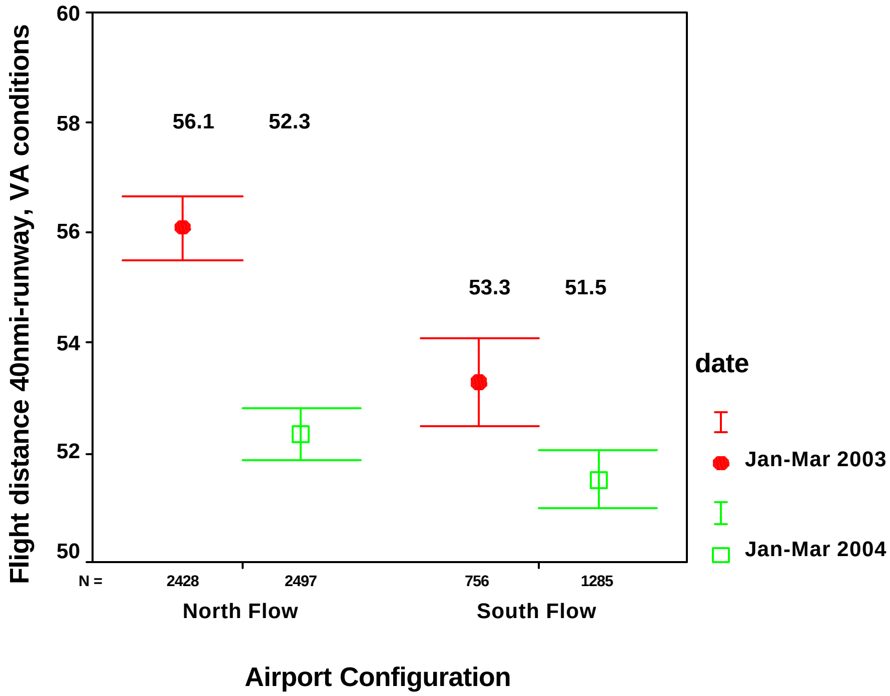

Figure 4-5. Actual Flight Distance, 40nmi Range Ring to Runway, VA conditions

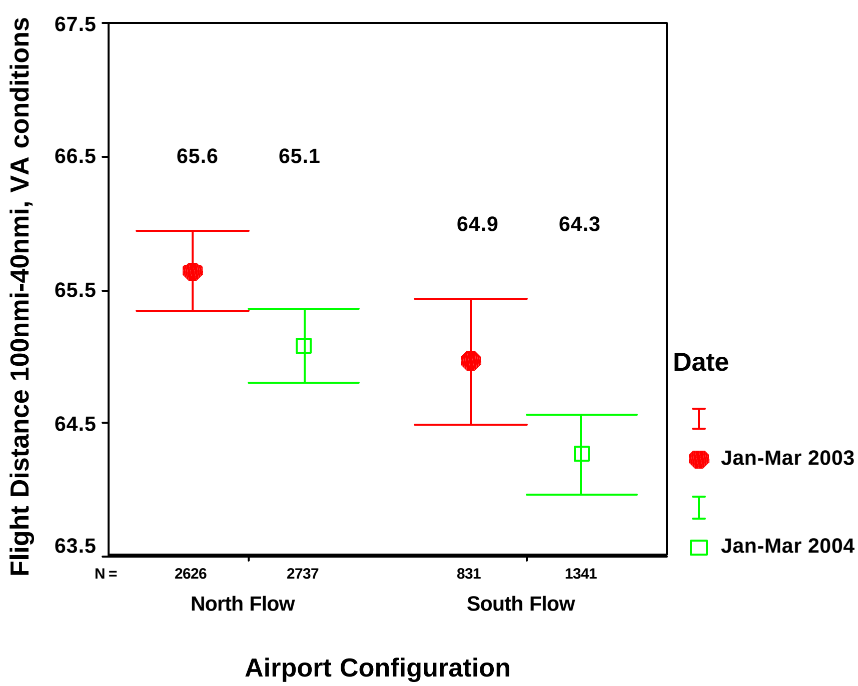

Figure 4-6. Actual Flight Distance, 100nmi to 40nmi Range Ring, VA conditions

Figures 4-7 and 4-8 show similar data for IA conditions. Here the results are inconclusive. The North flow case shows a decrease after implementation while the South flow case shows an increase. The 100 nmi to 40 nmi data shows a similar trend. There are many possible explanations for this trend. Because all IMC weather is not the same, there might be a difference in the severity of weather, which this analysis does not capture. Also, the current application (Enhanced Visual Approach) focuses on operation during VA, so we might expect that there be little or limited effect in IA.

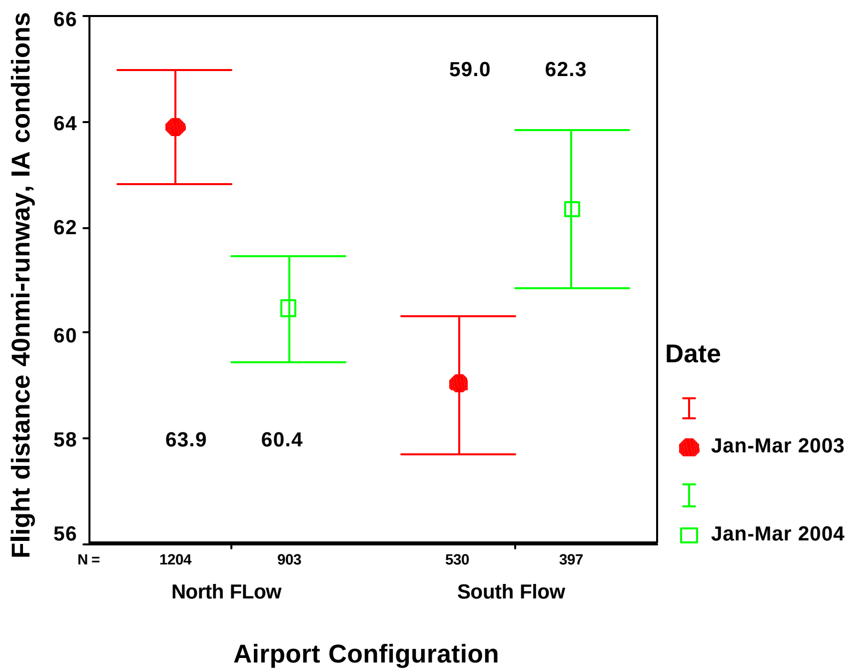

Figure 4-7. Actual Flight Distance, 40nmi Range Ring to Runway, IA conditions

We performed the same analysis on flight times and found similar trends. Table 4-2 summarizes the results in terms of flight time and distance changes. Negative values represent decreases in distance or time from the baseline. As a reminder the baseline period used is January 1, 2003 through March 12, 2003, and the post-implementation period is January 1, 2004 through March 12, 2004. All results are statistically significant to the 95 percent level unless otherwise noted.

4.1.2.3 More efficient overall flight operations

Problem: Lack of identification, speed, and heading information on current traffic displays also limits the pilot's knowledge of overall traffic flows. This lack of information can lead to inefficiencies in responding to ATC directions and poorer pilot traffic awareness.

Capability/Direct Impact: CDTI aids the pilot in monitoring overall traffic flows.

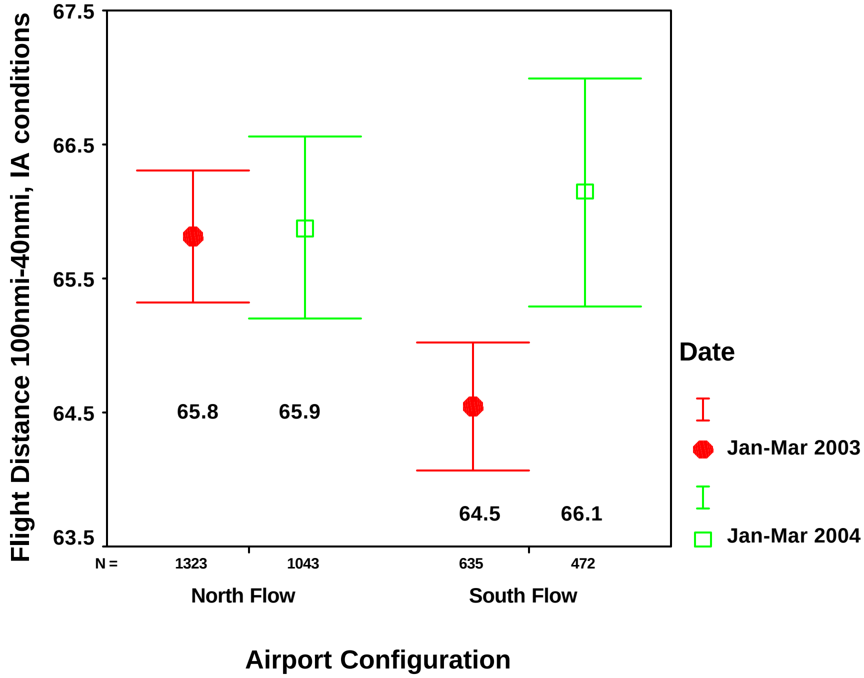

Figure 4-8. Actual Flight Distance, 100nmi to 40nmi Range Ring, IA conditions

Table 4-2. Flight Time and Distance Change at SDF

	40 nmi Range Ring to Runway		100 to 40 nmi Range Ring	
	Flight Distance Change (nmi)	Flight Time Change (sec)	Flight Distance Change (nmi)	Flight Time Change (sec)
VA North	-3.8	-60	-0.6	Not sig
VA South	-1.8	-27	-0.7	-14
IA North	-3.5	-42	Not sig	Not sig
IA South	+3.3	+94	+1.6	+41

Outcome/Benefit: Increased pilot ability to monitor overall traffic flows should increase pilot ability to respond quickly to ATC directions and fly the aircraft in an efficient manner during the entire flight. Increases in flight operation efficiency lead to increases in on-time performance and decreases in fuel usage.

Evidence: Our first examination of efficient overall flight operations considers fuel usage of UPS arrivals into SDF. There are many factors (e.g., flight distance, aircraft type, wind, weather, etc.) that affect fuel usage. To control for some of these factors, we compare the actual in-flight fuel burn with the planned fuel burn. The planned fuel burn during a flight should take many of the salient factors into account. However, any changes in the fuel planning algorithms would affect the comparison data.

We use planned and actual in-flight fuel burn values from UPS for arrivals into SDF. The baseline period is January 1, 2003 through March 12, 2003, and the post-implementation period is January 1, 2004 through March 12, 2004. Figure 4-9 presents four graphs with fuel burn results.

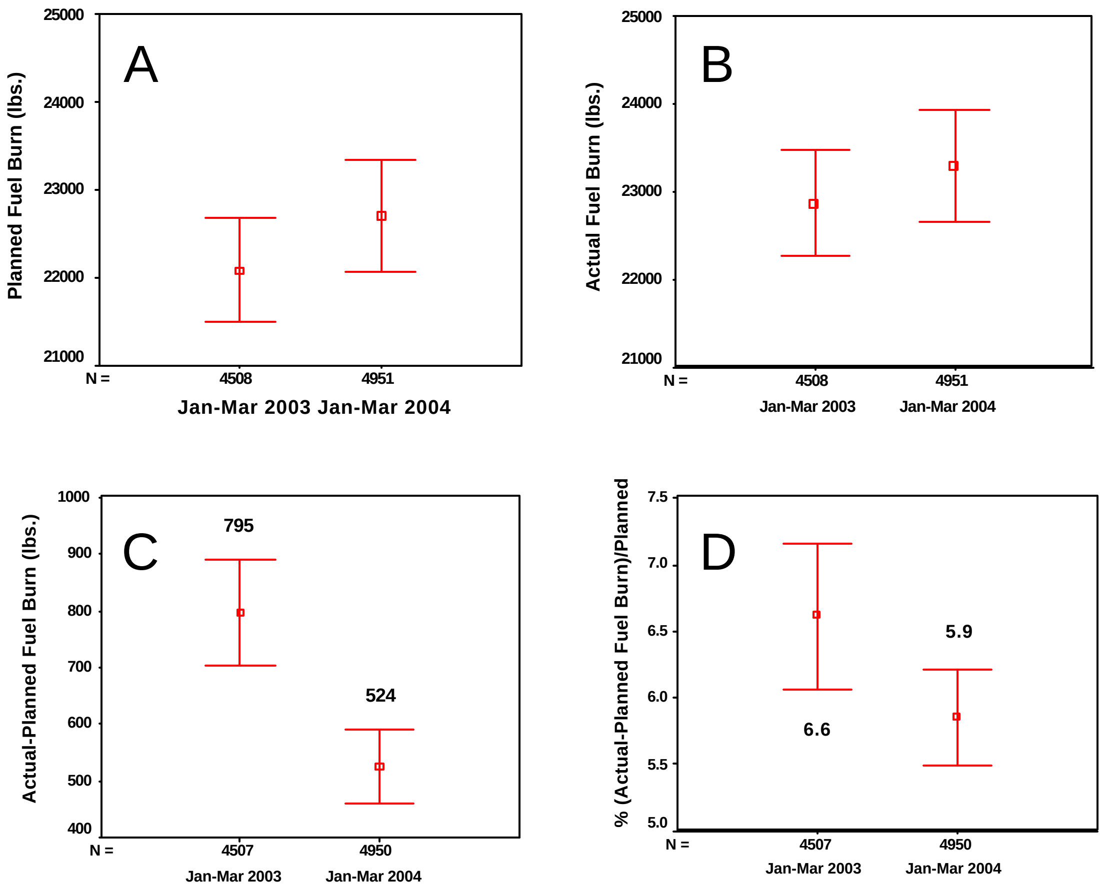

Figure 4-9. Comparison of Actual and Planned Fuel Burn for UPS Arrivals to SDF

Panel A of Figure 4-9 displays the mean planned in-flight fuel burn for flights in the baseline and post-implementation periods. Panel B shows the mean actual in-flight fuel burn. The error bars represent the 95 percent confidence intervals around the means. The results before and after implementation are statistically similar in both the planned and the actual fuel burn cases.

Panels C and D of Figure 4-9 compare the planned and actual fuel burns. Panel C shows the average difference between actual and planned, while Panel D displays this same difference as a percentage of the planned. In both cases, we detected a difference significant to the 95 percent level. On average, the actual fuel burn is in excess of the plan. The variation in the difference (as gauged by the standard deviation) is usually within 2000 lbs. The actual minus the planned in-flight fuel burn was on average 795 lbs. in the baseline period and decreased to 524 lbs. in the post-implementation period.

Panel D of Figure 4-9 displays the difference as a percentage of the plan. The percent difference of in-flight fuel burn should be less sensitive to variations in flight distance than the straight difference. In the baseline period, the percent difference of in-flight fuel burn is 6.6 percent, while in the post-implementation period it decreased to 5.9 percent. Although the error bars around the means for the two data sets overlap slightly, a T-test indicates that the difference in the means is statistically significant to the 95 percent level. This small difference in the means corresponds to an 11 percent decrease in excess fuel used.

The decreases evidenced in Panels C and D of Figure 4-9 suggest an increase in the predictability of planned fuel usage. Is this increase from more efficient operations because of CDTI use, or is there another cause? As use of CDTI continues, we will continue to measure this difference.

5 IMPROVED FLIGHT DURING SEVERE EN ROUTE WEATHER CONDITIONS

The disruptions in air traffic caused by hazardous en route weather are magnified by a lack of common understanding of weather information, as well as the intrinsic uncertainty of forecasts. There is a discrepancy between weather forecasts and the observed weather; there is a deficiency in the application of weather information to manage traffic flow in congested airspace. A commitment to operational change can be implemented by first improving the detection and forecasting of hazardous weather, although these improvements will be incremental. Secondly, the impacts of weather can be mitigated through improved distribution, display, and application of weather information. Finally, the integration of weather information into Decision Support Systems (DSSs) and automated tools will achieve the full potential for operational change by maximizing the capacity and efficiency of the airspace, even during disruptive hazardous weather events.

The OEP describes several initiatives designed to reduce the operational impact of en route severe weather. For this report we feature the Corridor Integrated Weather System (CIWS), which is currently under development by the MIT Lincoln Laboratory.

5.1 Corridor Integrated Weather System

5.1.1 System Description

The Corridor Integrated Weather System is a prototype Web application that takes advantage of the high density of existing FAA, National Weather Service (NWS), and Environment Canada weather sensors in the Great Lakes and Northeast Corridor region to provide traffic managers with accurate and timely information on storm locations and echo-top heights, along with 2-hour animated storm growth and decay forecasts. These state-of-the-art weather products help traffic managers to achieve more efficient tactical use of the airspace, reduce controller workload, and significantly reduce delay. The CIWS "tactical" traffic flow management products complement the longer-term "strategic" (2-6 hour) national Collaborative Convective Forecast Product (CCFP) forecasts that are also needed for flight planning and traffic flow management.

Thunderstorm impacts are most significant in areas where there is already significant air traffic congestion, such as the Northeast corridor. For 2004 the CIWS coverage area, illustrated in Figure 5-1, includes all of the seven major bottlenecks identified in the FAA's 2001 Airport Capacity Enhancement (ACE) Plan. Figure 5-1 also depicts the terminal and en route weather sensors used by CIWS. The rapid update rate of ASR-9 radars is used to detect rapidly growing cells, while the NEXRAD radars provide information on three-dimensional storm structure and boundary layer winds. Canadian radar data will also be included for the 2004 storm season. Data from lightning sensors and the Geostationary Operational Environment Satellite (GOES) are also used.

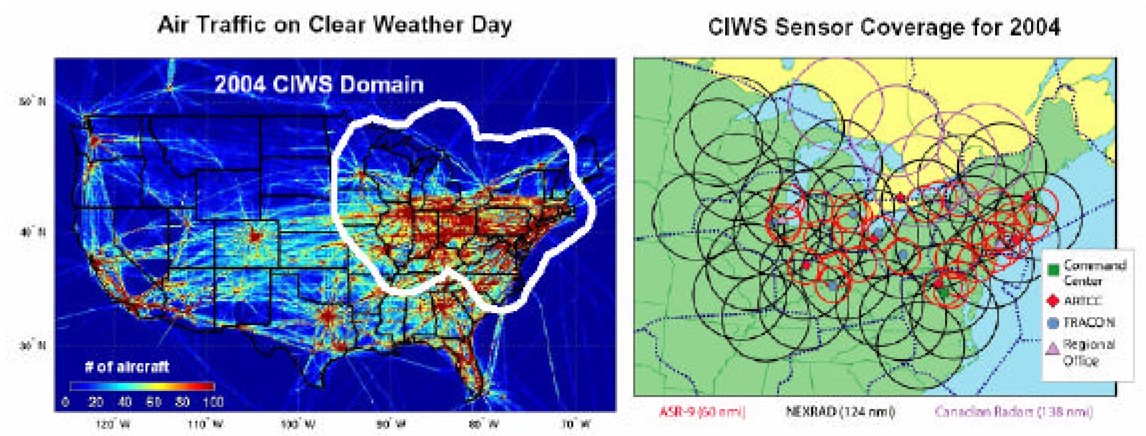

Figure 5-1. CIWS 2004 Coverage (left) and Radar Sensors (right)

The CIWS weather products and display features for 2004 were designed based on user feedback from demonstrations conducted in 2001 through 2003. Figure 5-2 presents a CIWS screen for the severe weather event of 22 August 2002, with various product windows displayed. The Echo Tops product (upper left window) shows the height of storms and has been used in conjunction with the radar-based precipitation data to permit aircraft to safely fly over storms, thus significantly reducing aviation delays. The upper right window shows the NEXRAD Vertically-Integrated Liquid Water (VIL) mosaic product displayed with storm motion vectors, satellite data, and two-hour forecast contours. The Regional Convective Weather Forecast (RCWF) provides two-hour animated forecasts in 15-minute intervals (lower left window). Key features of the forecast include the real time indication of forecast accuracy and an explicit depiction of areas of storm growth and decay. Storm growth (orange) and decay (blue) trends are also available as overlay options for NEXRAD Precipitation and Echo Tops products (the lower middle window of Figure 5-2). The lower right window shows the mosaiced ASR and NEXRAD VIL products with labels of echo top heights.

5.1.2 Benefits Case Study

A prototype CIWS, developed and operated by MIT Lincoln Laboratory under the supervision of the FAA, was used throughout 2003 to facilitate the quantification of operational benefits. Displays were provided at key ARTCCs (ZOB, ZDC, ZAU, ZBW, ZNY, and ZID), major TRACONS (New York City, Chicago, DTW, PIT, CLE, and CVG), and the Air Traffic Control System Command Center. Airline systems operations centers had access to the products through the Internet as well as via dedicated displays. CIWS benefits were assessed by on-site observations and interviews during major convective weather events, end-of-season user interviews, and analysis of flight track data. Reference 14 presents four detailed case studies of significant delay reduction events, and estimates the operational and economic benefits resulting from CIWS usage for each. We reproduce one of these benefits case studies here.

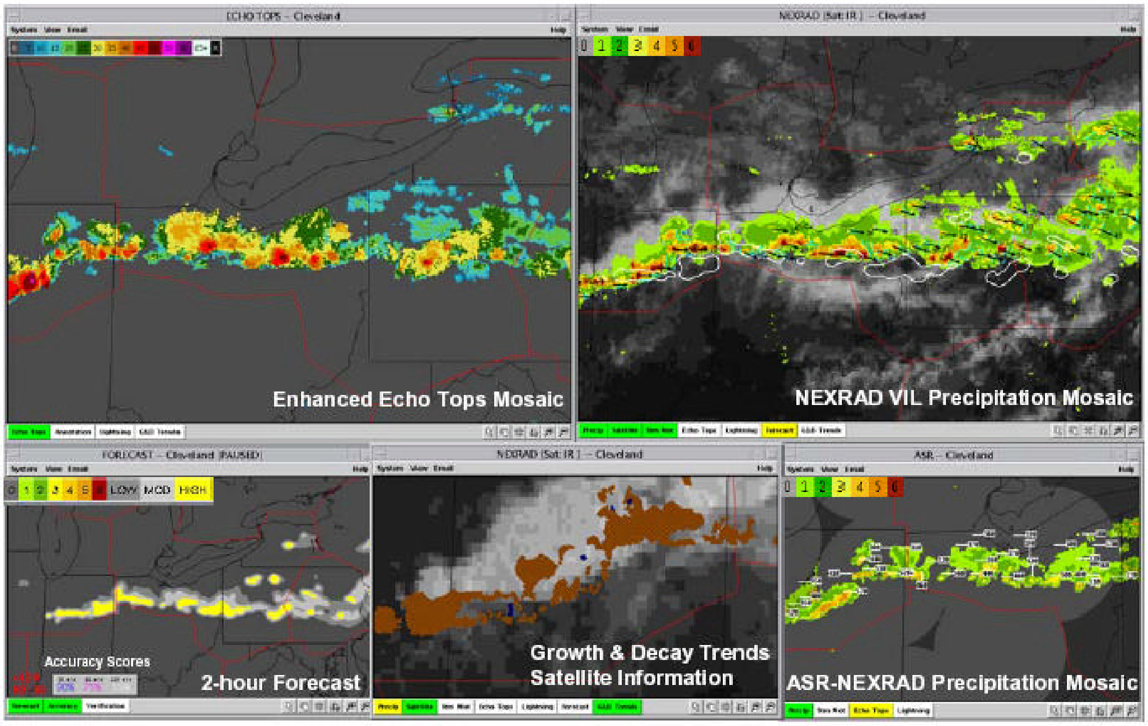

Figure 5-2. Representative CWIS Display, 22 August 2002

A persistent broken to solid line of strong thunderstorms moved eastward through the Great Lakes air traffic corridor throughout the day on 29 August 2003. The convective system became more organized during the afternoon hours, and by 1800 UTC a line of storms stretched from Ottawa, Canada southwestward to southern Indiana (Figure 5-3). In addition, smaller (but still formidable) storm clusters and isolated strong cells were present both west and east of the main squall line, further hampering air traffic operations. Storm gaps within the squall line opened on occasion as the system tracked eastward during the evening hours, but coverage and severity of the convective complex remained significant beyond 0200 UTC on 30 August. Air traffic delays were significant throughout the Great Lakes and Northeast corridors, because of both en route and terminal storm impacts.

The intensity and extent of the squall line by late afternoon was such that it severely limited routing options for east-west traffic throughout the Midwest, Northeast, and Mid-Atlantic regions. Of particular concern was traffic to and from airports within ZBW airspace, where strong convection threatened to completely block routes beyond the east coast. Based upon the 2 hr CCFP forecast valid at 2100 UTC, conditions were expected to worsen for ZBW operations, as previously forecasted regions of "low-coverage" convection were predicted to fill in and completely block east-west routes through western portions of this en route Center (Figure 5-4).

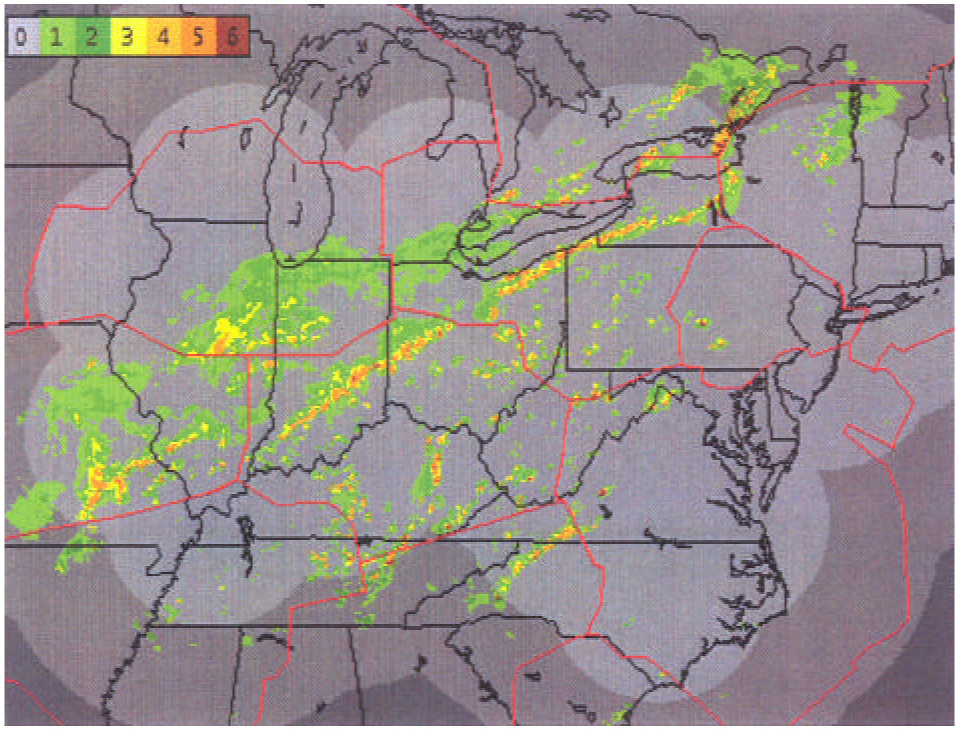

Figure 5-3. Thunderstorm coverage, 1800 UTC on 29 August 2003.

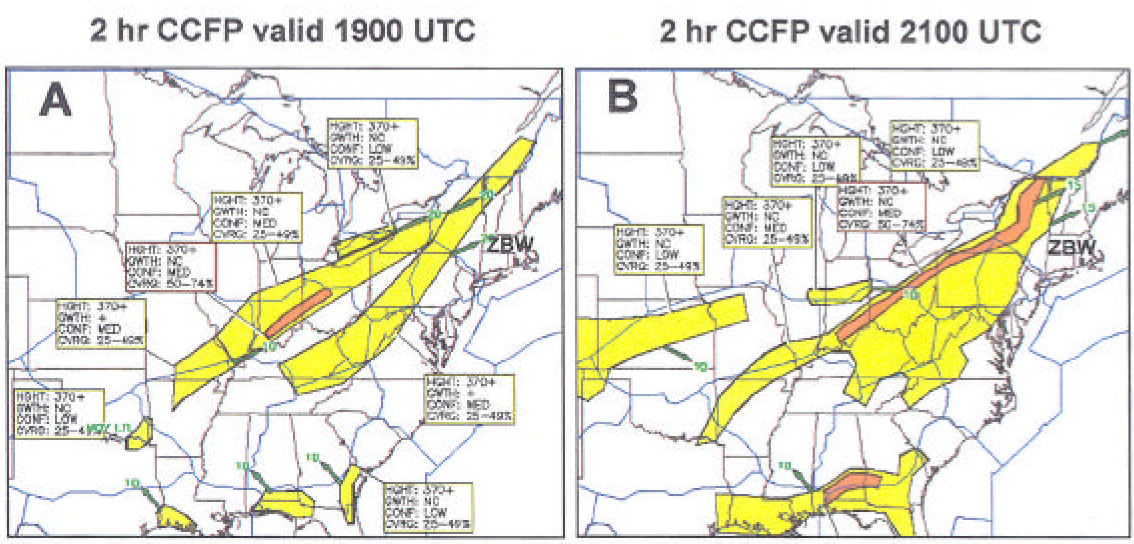

Figure 5-4. 1 hr CCFP forecast valid at (a) 1900 UTC and (b) 2 100 UTC on 29 August 2003. *By 2 100 UTC, this product predicted with "medium" confidence increased coverage of significant convection, forming a solid line completely blocking western ZBW airspace.*

During post-event interviews, ZBW traffic managers stated that contrary to the CCFP forecast, the CIWS 2-hour convective forecast product predicted an operationally useful storm gap through the convective line near Syracuse (SYR), New York. As the existence of this gap was predicted to persist with each successive 5 min update of the RCWF product, and through each 15-min forecast increment from +15 to +120 min, ZBW traffic managers gained confidence in moving significant streams of eastbound and westbound traffic through the weather opening in upstate New York (Figure 5-5). The traffic managers interviewed pointedly remarked that moving eastbound *and* westbound traffic through such a relatively small gap in weather was a rare occurrence.

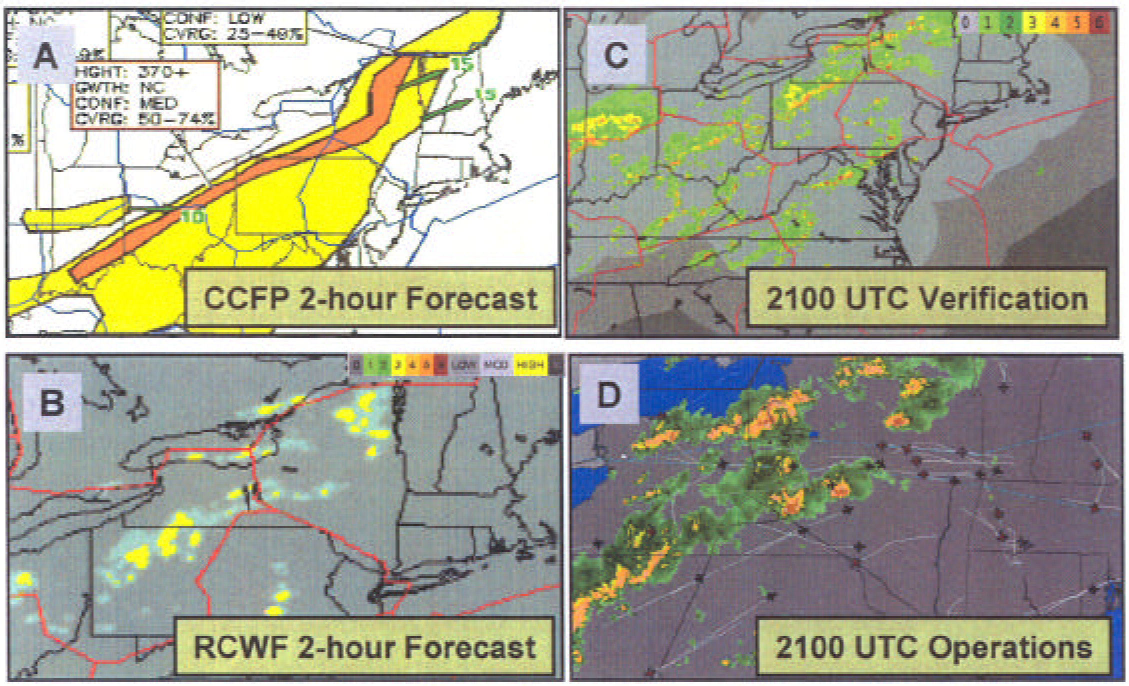

Figure 5-5. CCFP Forecast, CIWS Products, and Flight Tracks, 29 August 2003. *(a) 2 hr CCFP forecast valid 2100 UTC (b) 2 hr CIWS RCWF product valid 2100 UTC (c) CIWS NEXRAD VIL Precipitation at 2100 UTC (d) FlightExplorer flight track and WSI composite reflectivity information at 2100 UTC depicting Boston Logan, Bradley, and Manchester arrivals and departures.*

However, they noted that this gap was their only western option for entering and exiting ZBW airspace, so significant traffic was moved through this region over a prolonged period. Additionally, it was revealed by traffic managers during the post-event interview that had the CIWS forecast of a persistent storm gap in the convective line not been available, traffic would have "at best" trickled to/from the west and all airports within ZBW airspace would have been restricted by ground stops. Moreover, since CIWS facilitated high capacity traffic flows on routes through the storm gap in upstate New York, significant ZBW departure backlogs were prevented. As a consequence, the ZBW ARTCC was also able to accept LGA westbound departures via this storm gap, thus helping to alleviate gridlock conditions at this airport caused by storms in ZNY airspace.

5.1.3 Economic Benefits Estimate

The benefit for this storm event was that westbound departures from ZBW airports were able to avoid ground stop restrictions, once it was determined that the storm gap across Upstate New York would persist. Moreover, traffic managers stated that confidence in the CIWS forecast, based on accurate verifications, allowed them to open routes to eastbound and westbound traffic at significantly greater capacities.

A queuing model was used to quantify delay savings attributable to CIWS for three ZBW airports: Boston (BOS), Bradley (BDL), and Manchester (MHT). Demand profiles for arrivals and departures for each airport were determined by enumerating flights on the nearest, non-weather, non-delay weekday. All traffic traveling preferred routes along the east coast, away from the 29 August storm impact region, were removed from all calculations. To model actual delays during the storm event, capacity profiles for these same routes through the storm impact region were determined based upon actual air traffic through western ZBW airspace (i.e., utilizing the persistent storm gap). To model delay for the case without CIWS benefits, arrival and departure capacities at each airport were reduced with the assumptions that an initial 2 hr ground stop for arrivals would have been implemented, followed by reduced traffic rates during the rest of the benefit period. To estimate the traffic flow reduction associated with the ground stop, arrival and departure capacities for each airport were reduced by 50 and 75 percent, respectively, of the observed flight counts through western ZBW airspace. The benefit period for each airport was based upon the time at which the first and last arrival/departure was observed using routes through the CIWS-forecasted storm gap. Finally, westbound departures from LGA airport, which used the ZBW storm gap, were also modeled. Similar logic was used to estimate the capacity had the gap suggested by CIWS not been used.

Total delay savings for BOS, BDL, MHT, and LGA on 29-30 August 2003 are presented in Table 5-1. In all, over 1,000 hours of delay were avoided, resulting in cost savings of nearly $6,000,000.[6] The CIWS delay savings estimated for this storm event are considered conservative since additional ZBW airports such as Providence (PVD) and Portland, ME (PWM) were not included in this study. Arrivals and departures from these airports were also observed entering and exiting ZBW airspace by way of the storm gap across upstate New York.

Table 5-1. CIWS Delay Reduction Benefits, 29-30 August 2003

Airport	Duration (hr)	Arrival Delay Savings (hr)	Departure Delay Savings (hr)	Total Delay Savings (hr)	Cost Savings
BOS	6 (arrivals), 7 (departures)	358.0	326.6	684.6	$3,761,373
BDL	5 (arrivals), 8 (departures)	77.6	137.2	214.8	1,180,067
MHT	7 (arrivals), 7 (departures)	101.7	64.5	166.2	913,006
LGA	2 (departures)	-	9.3	9.3	51,009
	Total	*537.3*	*537.6*	*1,074.9*	*$5,905,455*

[6] In addition to these figures, Reference 14 reports a downstream delay savings equal to 80 percent of the total delay savings reported here.

ACRONYMS

AAR	Airport Acceptance Rate
ACARS	ARINC Communications and Address Reporting System
ACDF	Adjacent Center Data Feed
ACE	Airport Capacity Enhancement
ACM	Adjacent Center Metering
ADS-B	Automatic Dependent Surveillance – Broadcast
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASDE-X	Airport Surface Detection Equipment - Model X
ASPM	Aviation System Performance Metrics
ASQP	Airline Service Quality Performance
ATA	Air Transport Association
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATL	Hartsfield-Jackson Atlanta International Airport
ATIDS	Airport Target Identification System
ATO	Air Traffic Organization
ATOP	Advanced Technologies and Oceanic Procedures
AUS	Austin Bergstrom International Airport
BDL	Bradley International Airport
BOS	Boston Logan International Airport
BRO	Brownsville International Airport
BTR	Baton Rouge Metropolitan Airport
CCFP	Collaborative Convective Forecast Product
CCLD	Core Capability Limited Deployment
CCSD	Common Constraint Situation Display
CDTI	Cockpit Display of Traffic Information
CHI	Computer Human Interface
CIWS	Corridor Integrated Weather System
CLE	Cleveland Hopkins International Airport

CPDLC	Controller-Pilot Data Link Communications
CRABS	Comprehensive Real-time Analysis of Broadcast Systems
CRP	Corpus Christi International Airport
CVG	Cincinnati/Northern Kentucky International Airport
DEN	Denver International Airport
DFW	Dallas/Fort Worth International Airport
DSS	Decision Support System
DTW	Detroit Wayne County Metropolitan Airport
DoD	Department of Defense
ETMS	Enhanced Traffic Management System
EA	Extreme Arc
ETA	Estimated Time of Arrival
FANS	Future Aviation Navigation System
FCA	Flow Constrained Area
FEA	Flow Evaluation Area
FedEx	Federal Express
FFP1	Free Flight Phase One
FFPO	Free Flight Program Office
GOES	Geostationary Operational Environment Satellite
GPD	Graphic Plan Display
GPT	Gulfport International Airport
HF	High Frequency
HRL	Valley (Harlingen) International Airport
IA	Inner Arc
IA	Instrument Approach
IAH	George Bush Intercontinental Airport
IDU	Initial Daily Use
IFR	Instrument Flight Rules
IOC	Initial Operational Capability
JHUAPL	Johns Hopkins University Applied Physics Laboratory
LAX	Los Angeles International Airport
LGA	New York La Guardia Airport

LFT	Lafayette Regional Airport
MA	Meter Arc
MCO	Orlando International Airport
MEM	Memphis International Airport
MFE	McAllen Miller International Airport
MHT	Manchester Airport
MIA	Miami International Airport
MIT	Miles in Trail
MIT	Massachusetts Institute of Technology
MLAT	ASDE-X Multilateration
MOB	Mobile Airport
MSP	Minneapolis-St.Paul Airport
MSY	Louis Armstrong New Orleans International Airport
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NEXRAD	Next Generation Weather Radar
NWA	Northwest Airlines
NWS	National Weather Service
OA	Outer Arc
OEP	Operational Evolution Plan
OOOI	Out-Off-On-In
ORD	Chicago O’Hare International Airport
PIT	Pittsburgh International Airport
PVD	Theodore Francis Green State Airport (Providence)
MCO	Orlando International Airport
MSODL	Multi-sector Oceanic Data Link
PHL	Philadelphia International Airport
RCWF	Regional Convective Weather Forecast
RNP	Required Navigational Performance
RO	Radio Operator
SAT	San Antonio Airport
SDF	Louisville International Standiford Field

SF-21	Safe Flight-21
SOC	System Operations Control
STMS	Surface Traffic Management System
SUA	Special Use Airspace
SYR	Syracuse International Airport
TCAS	Traffic Alert and Collision Avoidance System
TBM	Time-Based Metering
TFM	Traffic Flow Management
TFR	Temporary Flight Restrictions
TMA	Traffic Management Advisor
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
TSD	Tactical Situation Display
UPS	United Parcel Service
URET	User Request Evaluation Tool
UTC	Universel Temps Coordonnè (Coordinated Universal Time)
VA	Visual Approach
VFR	Visual Flight Rules
VHF	Very High Frequency
VIL	Vertically-Integrated Liquid Water
ZAN	Anchorage Center
ZAU	Chicago Center
ZBW	Boston Center
ZDV	Denver Center
ZFW	Fort Worth Center
ZHU	Houston Center
ZID	Indianapolis Center
ZJX	Jacksonville Center
ZKC	Kansas City Center
ZLA	Los Angeles Center
ZMP	Minneapolis Center
ZNY	New York Center

ZOA	Oakland Center
ZOB	Cleveland Center
ZTL	Atlanta Center

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